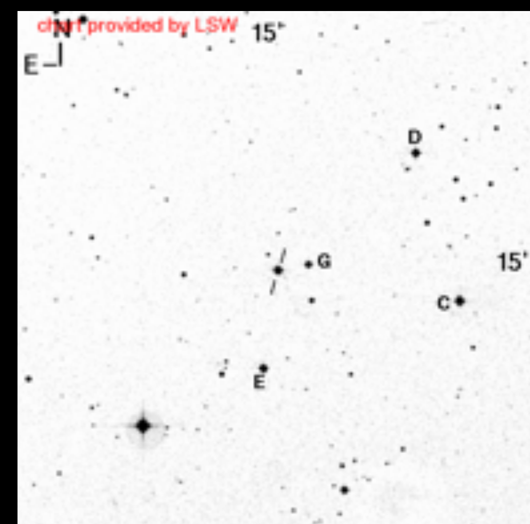
Quasar evolution at high redshift

Ian McGreer
Steward Observatory

a brief history of quasars

a brief history of quasars

1964: 1st quasar redshift



1968: z=2 quasars


~1970: BH accretion theory

a brief history of quasars

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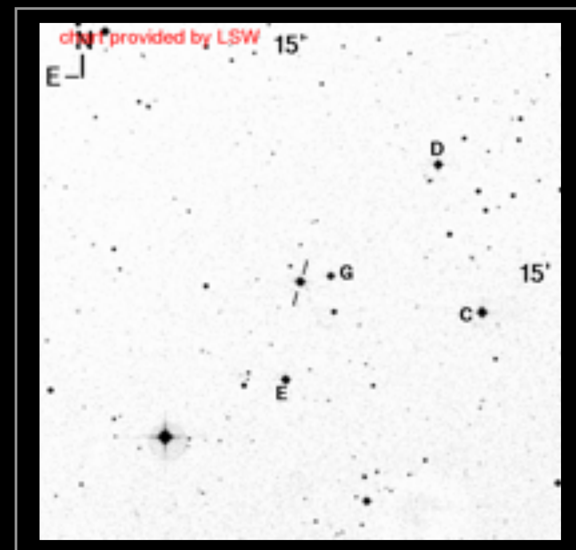

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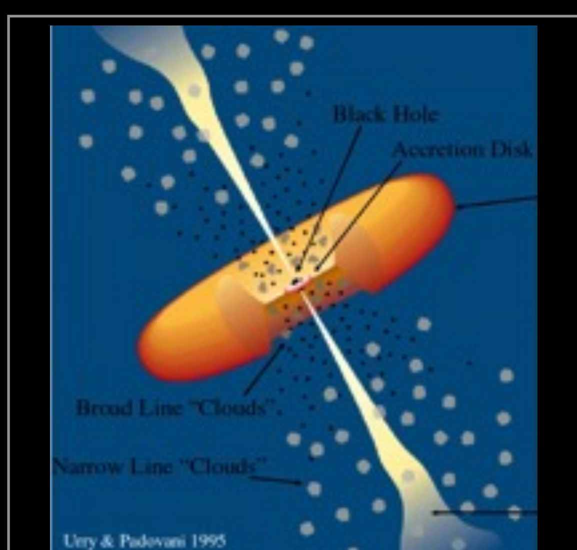
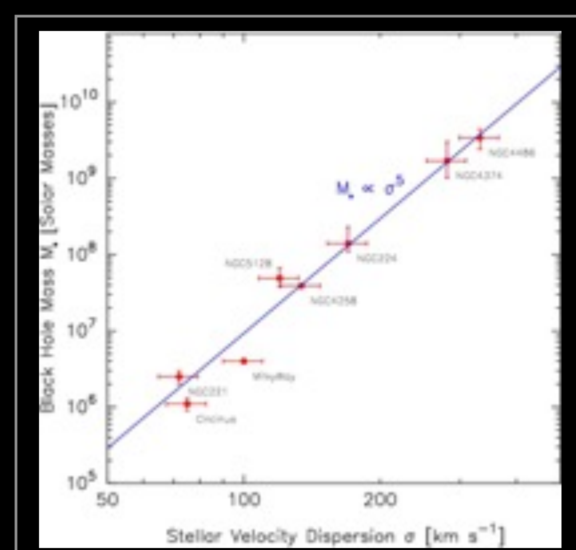


early 1990s: unification



late 1990s: BH-galaxy correlations

a brief history of quasars

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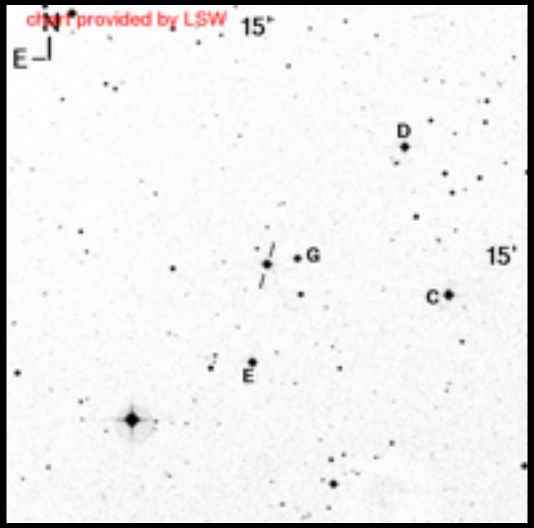

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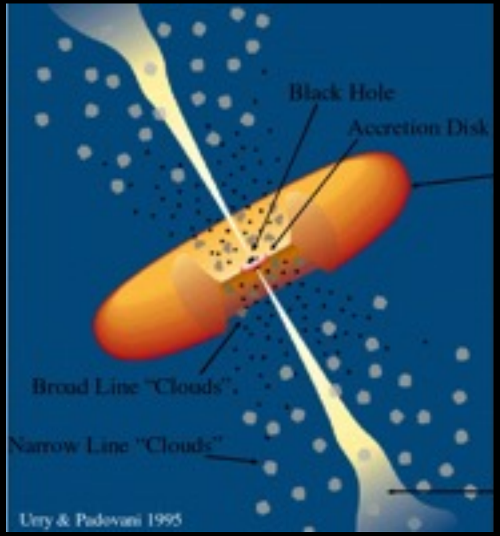

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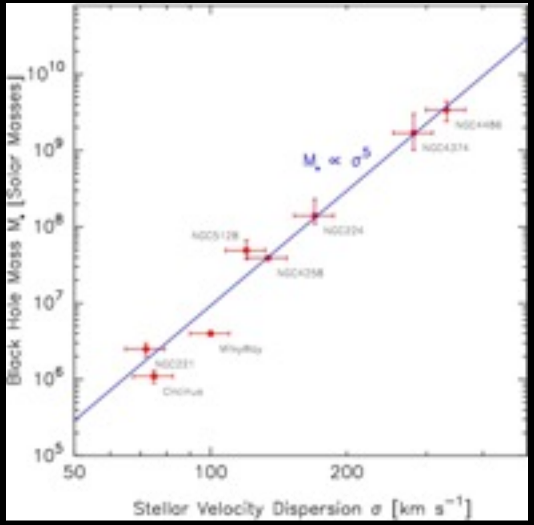
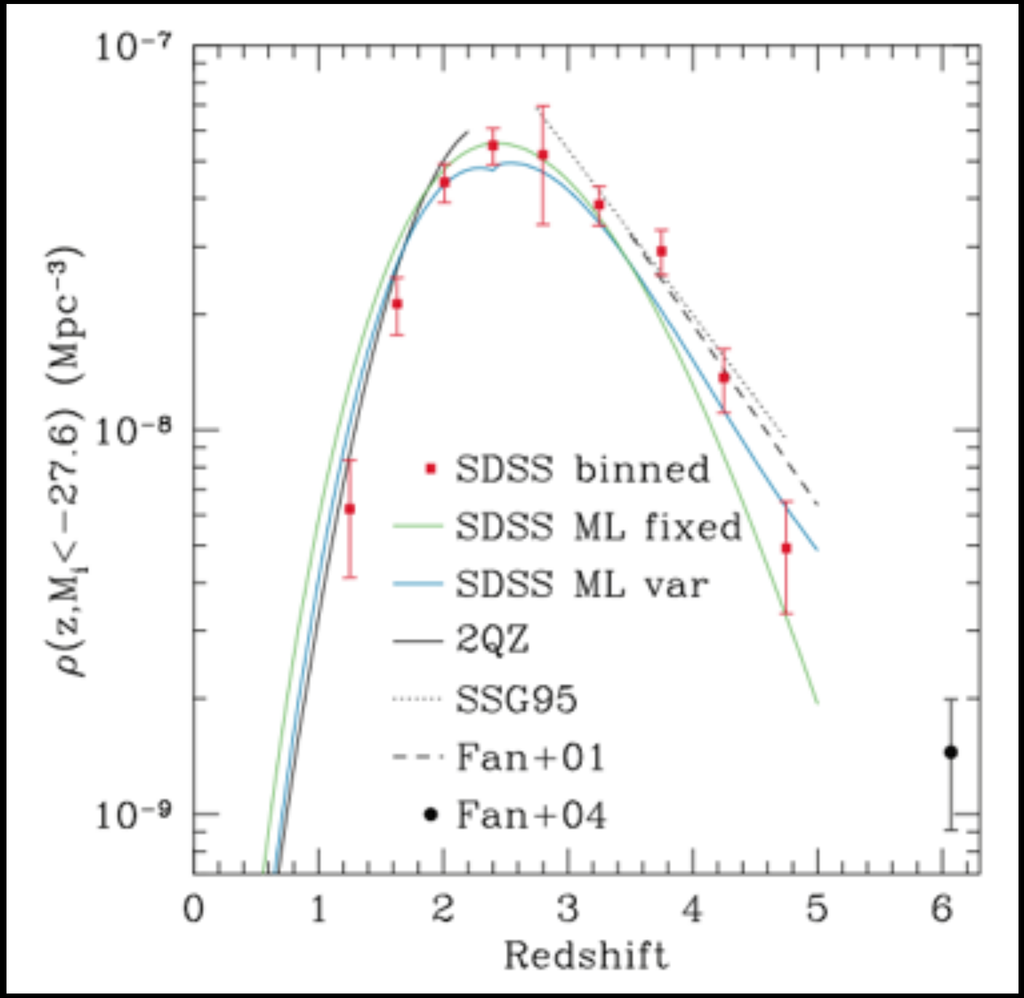


late 1990s: BH-galaxy correlations

2000s: reionization epoch

one Gyr of quasar evolution

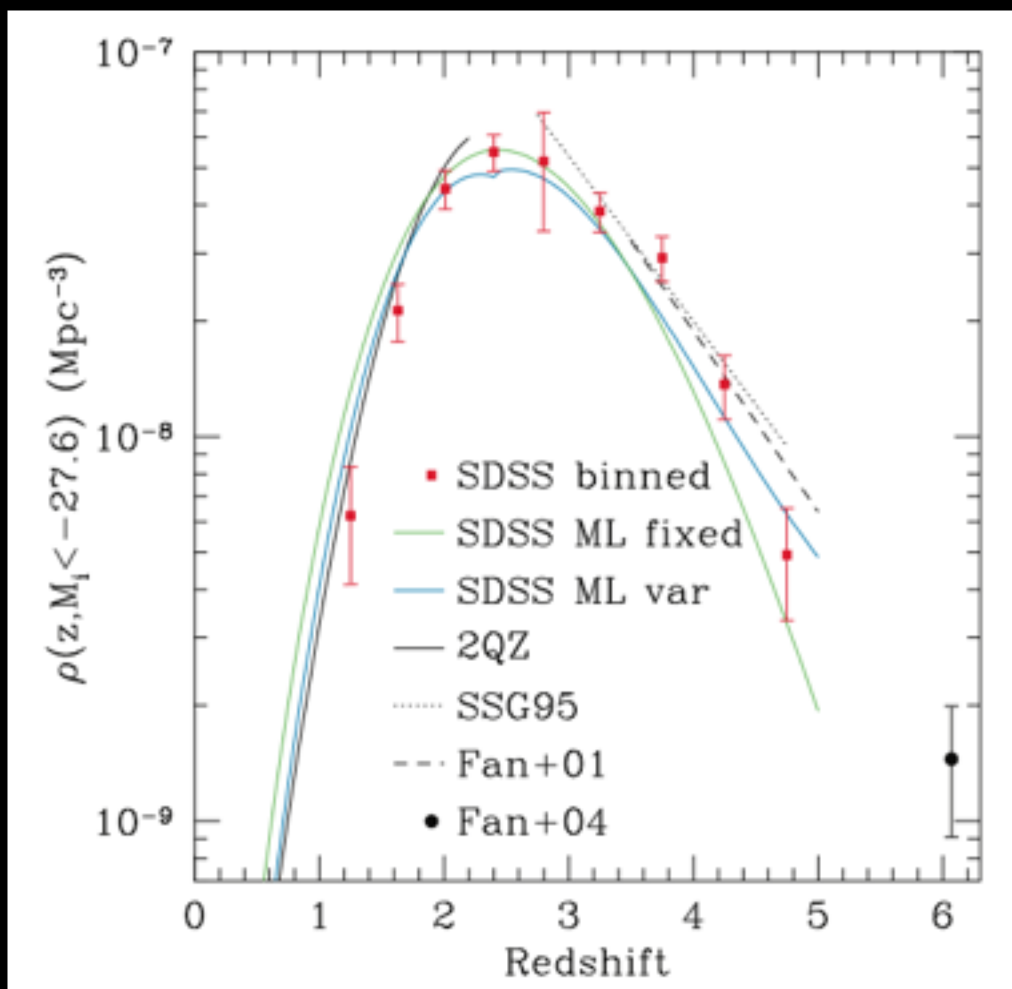
density of luminous quasars



Richards+06 (SDSS)

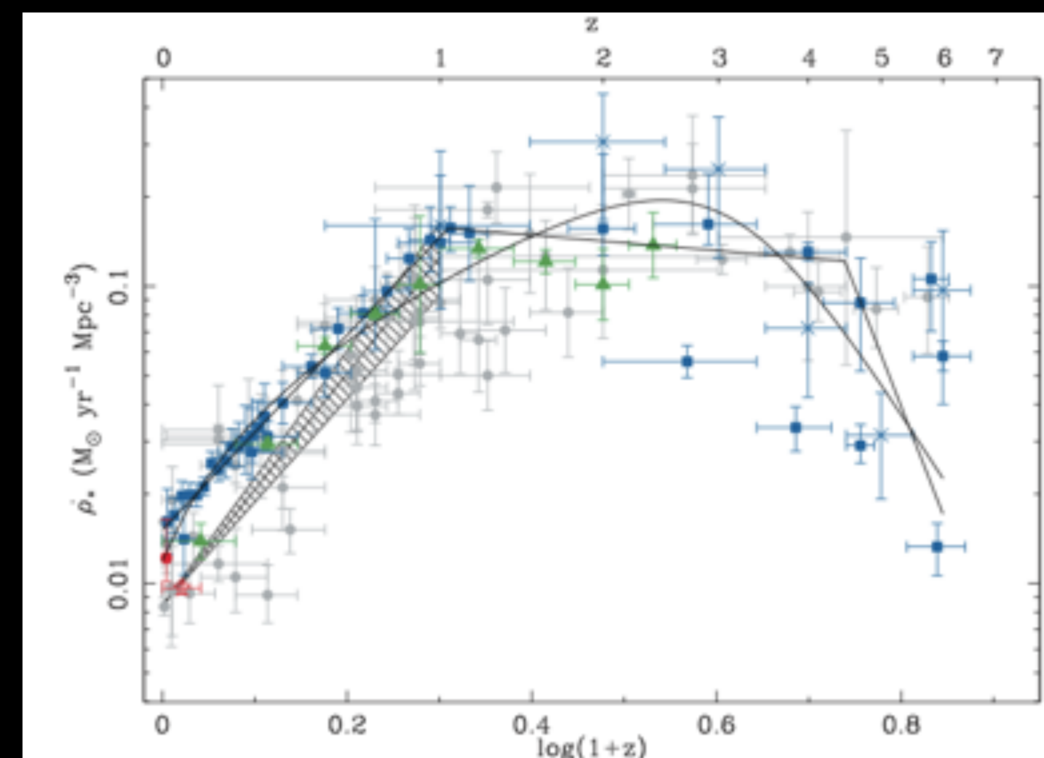
one Gyr of quasar evolution

density of luminous quasars



Richards+06 (SDSS)

cosmic star formation density



Hopkins & Beacom (2006)

Characterizing the growth of SMBHs over cosmic time

seeds, role of mergers, lifetimes, outflows/winds/feedback, spin, radiative efficiency, spectral energy distributions, halo occupation…

Characterizing the growth of SMBHs over cosmic time

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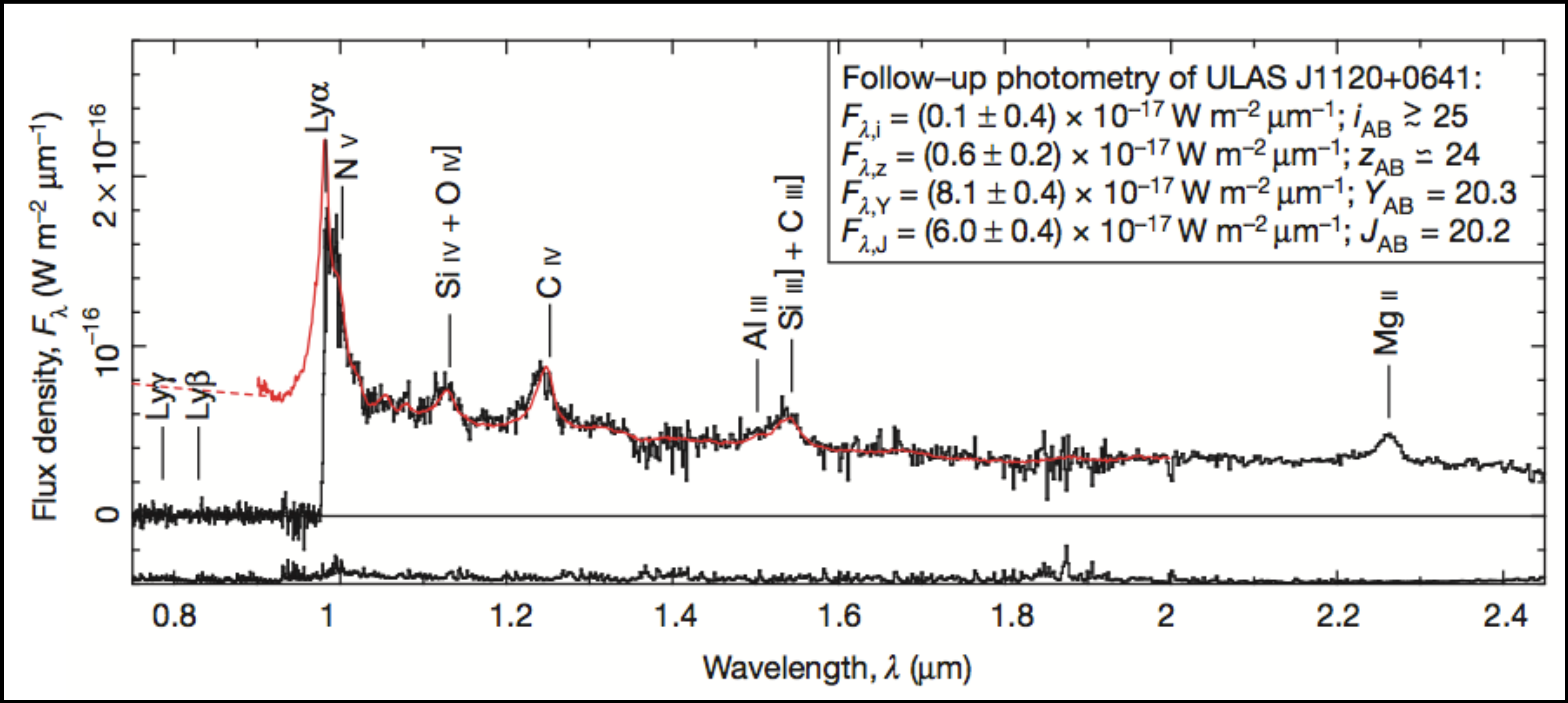
Multiwavelength surveys, luminosity functions, clustering

Part 1: Quasar SEDs

Do quasar SEDs evolve?

- no change in UV/optical spectra for *observed* quasars to z~7
- nuclear region already chemically enriched (Kurk+07,Jiang+07,de Rosa+12)



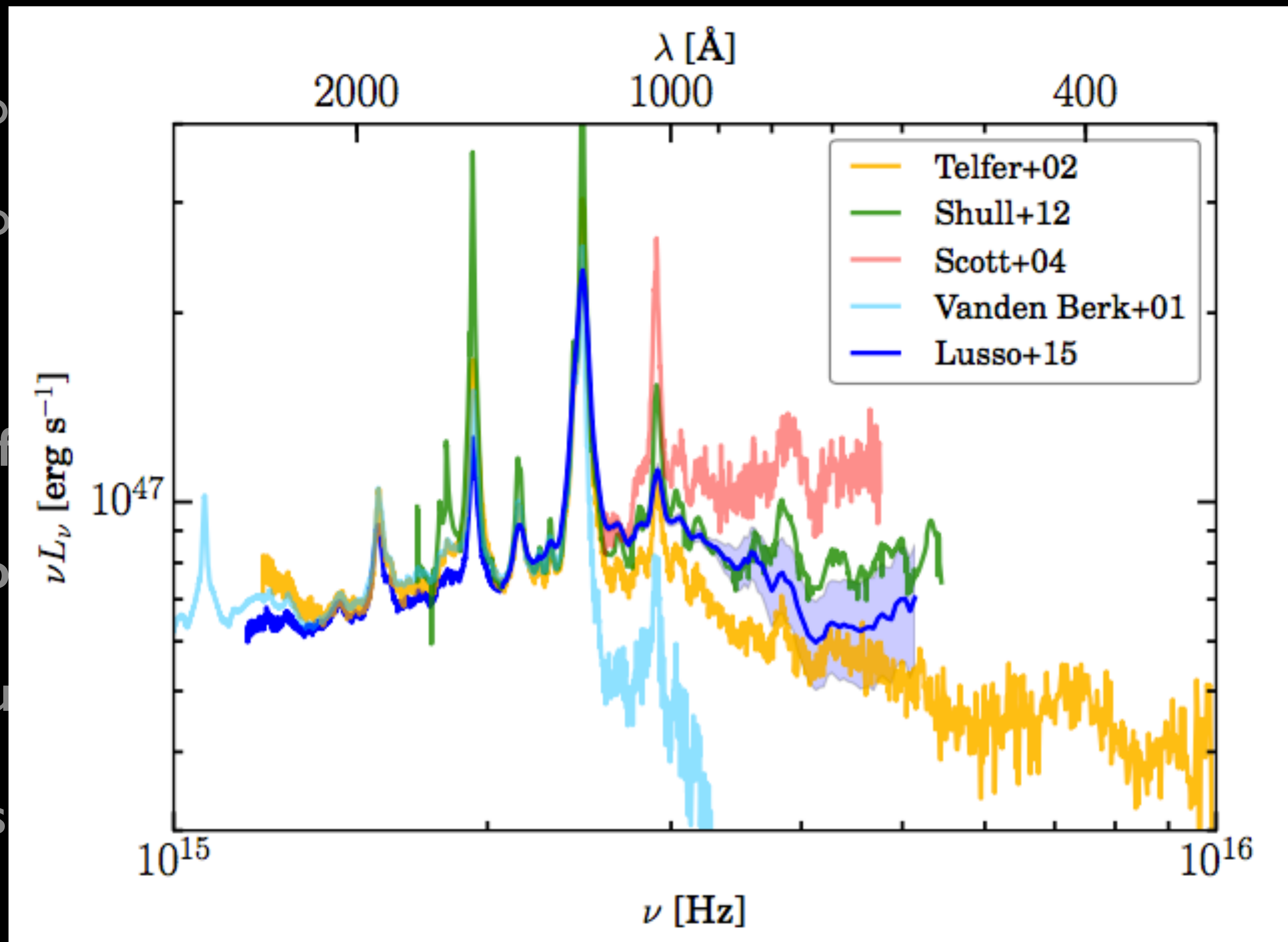
Mortlock+11

Do quasar SEDs evolve?

- the ionizing continuum is poorly constrained
- Lya forest: PCA methods (Lee+12, Paris+12), differential evolution (Becker+13)
- mean spectral shape: UV spectra from space
  - **Telfer+02**: <z> ~1, 80-300 objects, α_{uv}=-1.57
  - **Scott+04**: z<0.7, far-UV (FUSE) α_{uv}=-0.6, α_{uv} ~ L_{uv}
  - **Shull+12/Stevans+14**: <z>~0.4, 22 (159) AGN (COS), α_{uv}=-1.41
  - **Lusso+15**: z~2.4, 53 SDSS quasars (COS), α_{uv}=-1.7

Do quasar SEDs evolve?

- the io
- Lya fo ... er+13)
- mean
  - Telf
  - Sco
  - Shu ... .41
  - Lus



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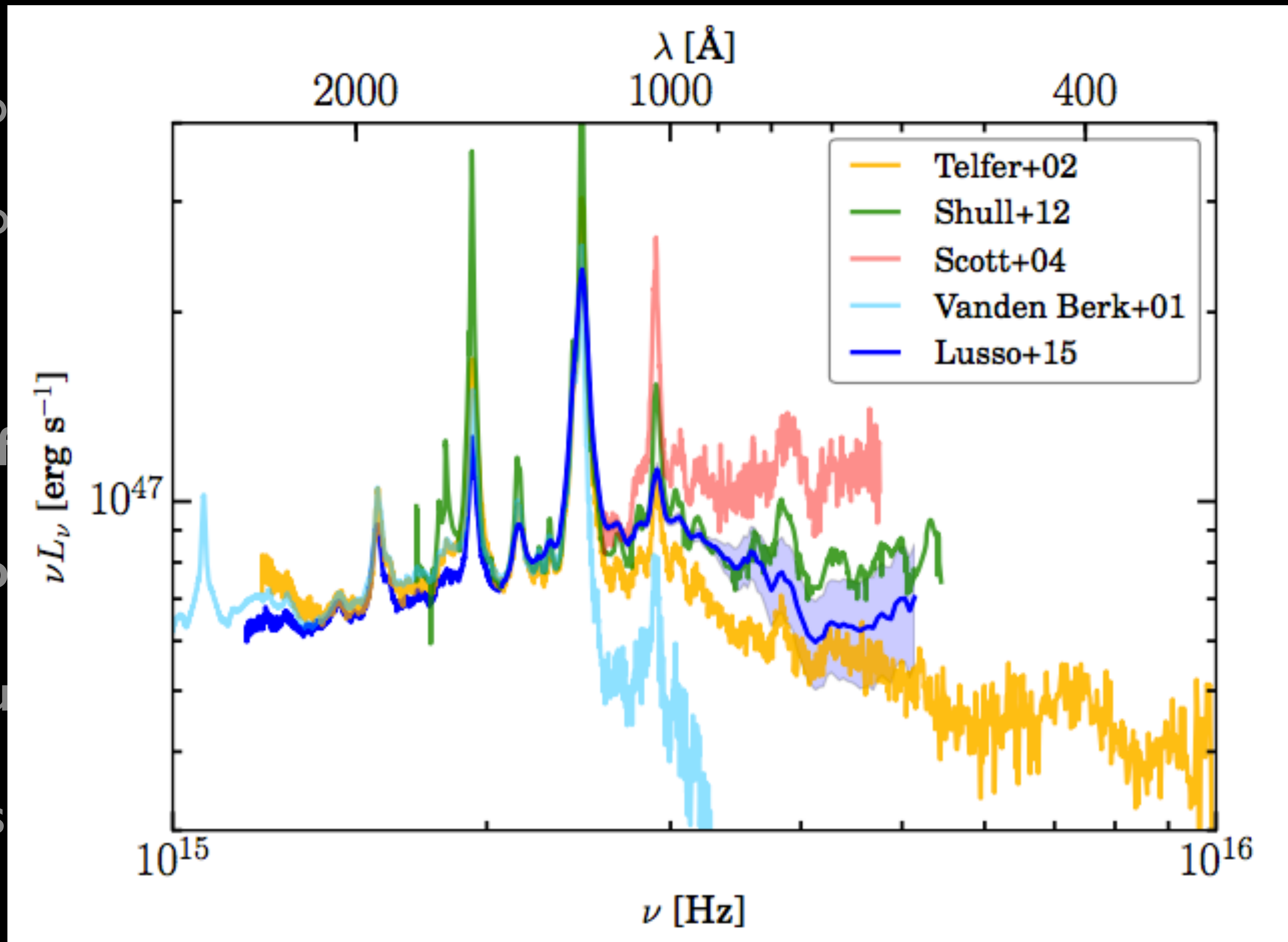
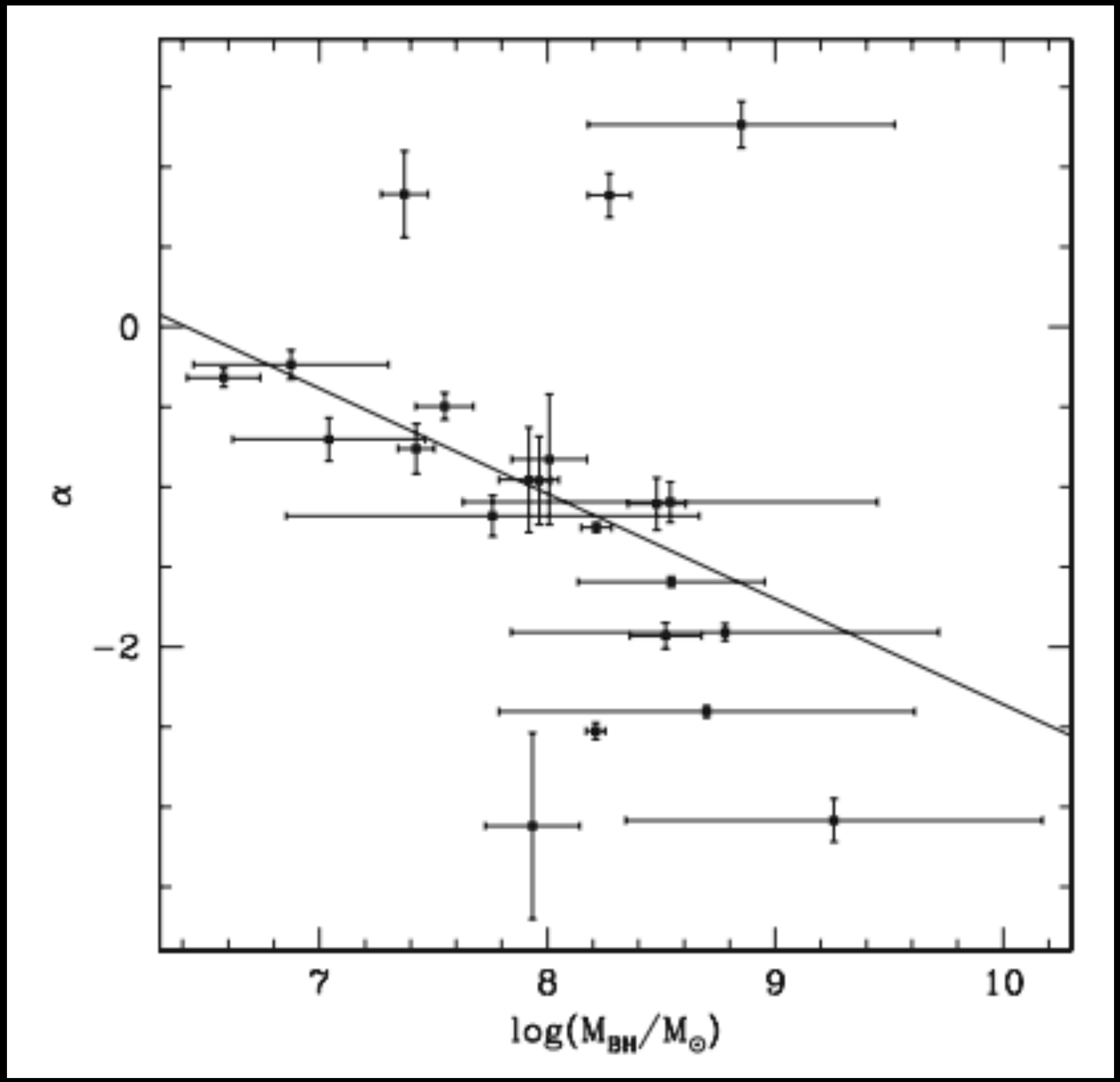


inhomogeneous samples, low-z, small numbers, no dust corrections

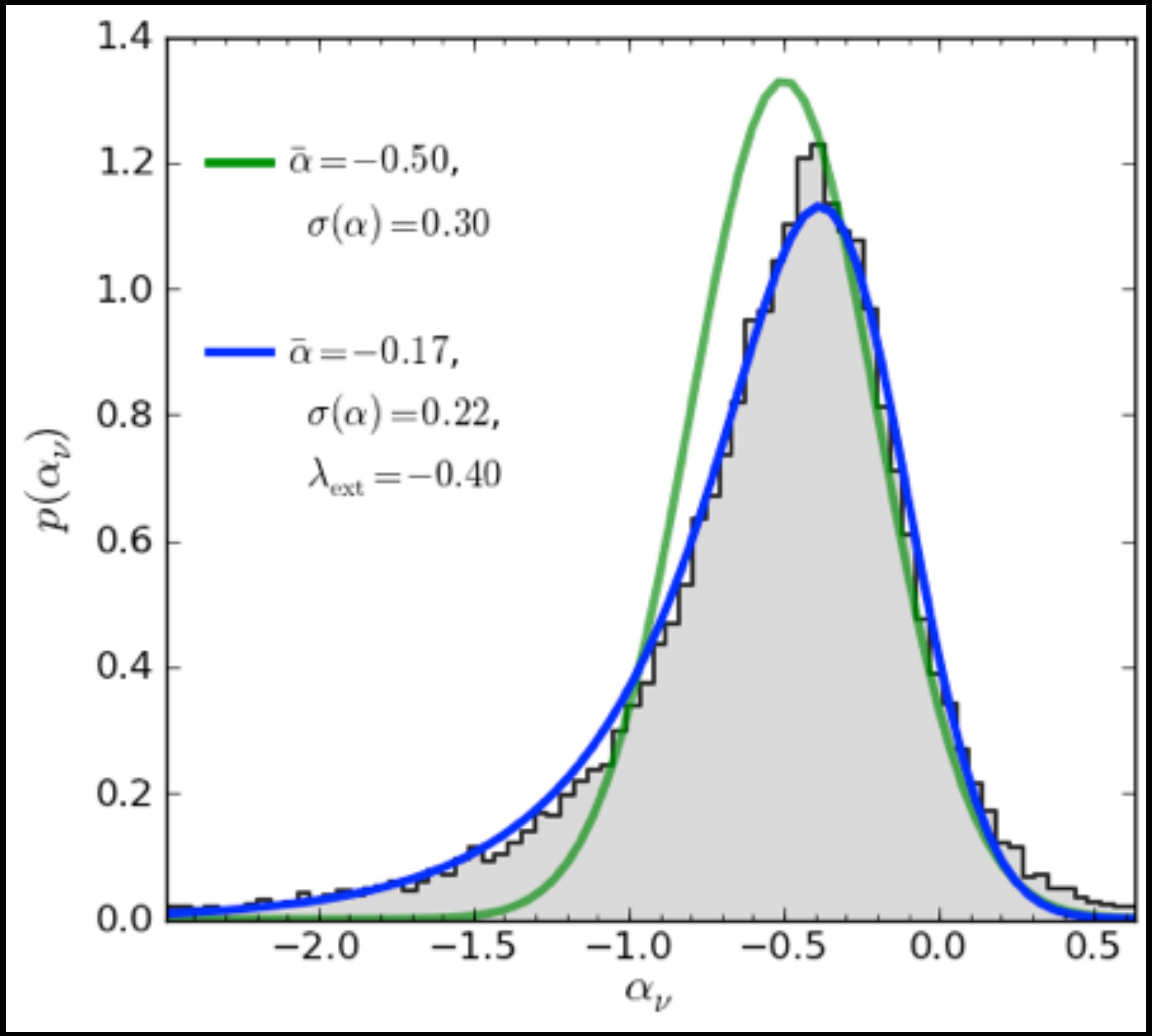
characterizing far-UV slopes

correlations



Scott+04
(also Wyithe & Bolton 2010)

dust

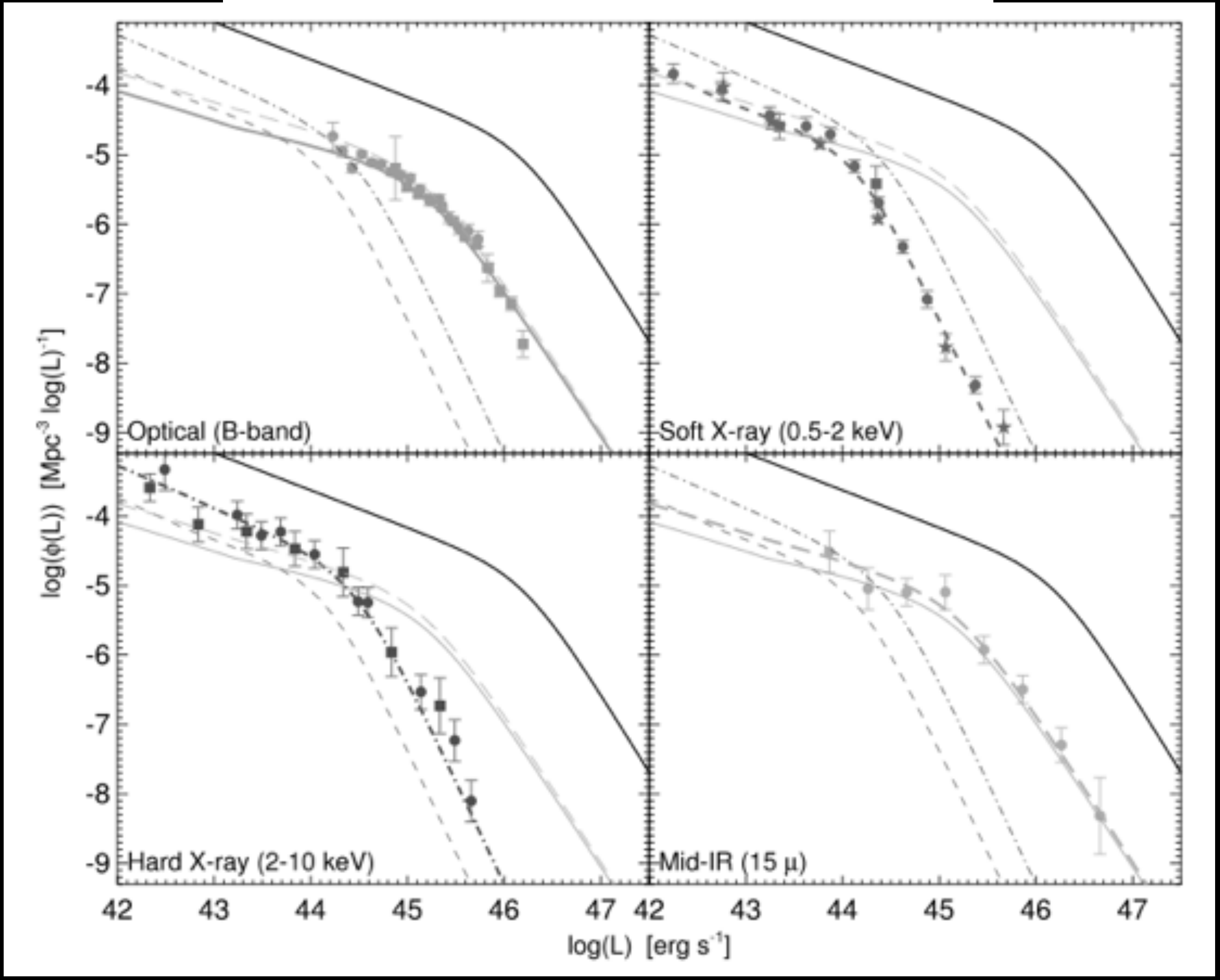


Hopkins+04, IDM+ in prep

Part II: the luminosity function

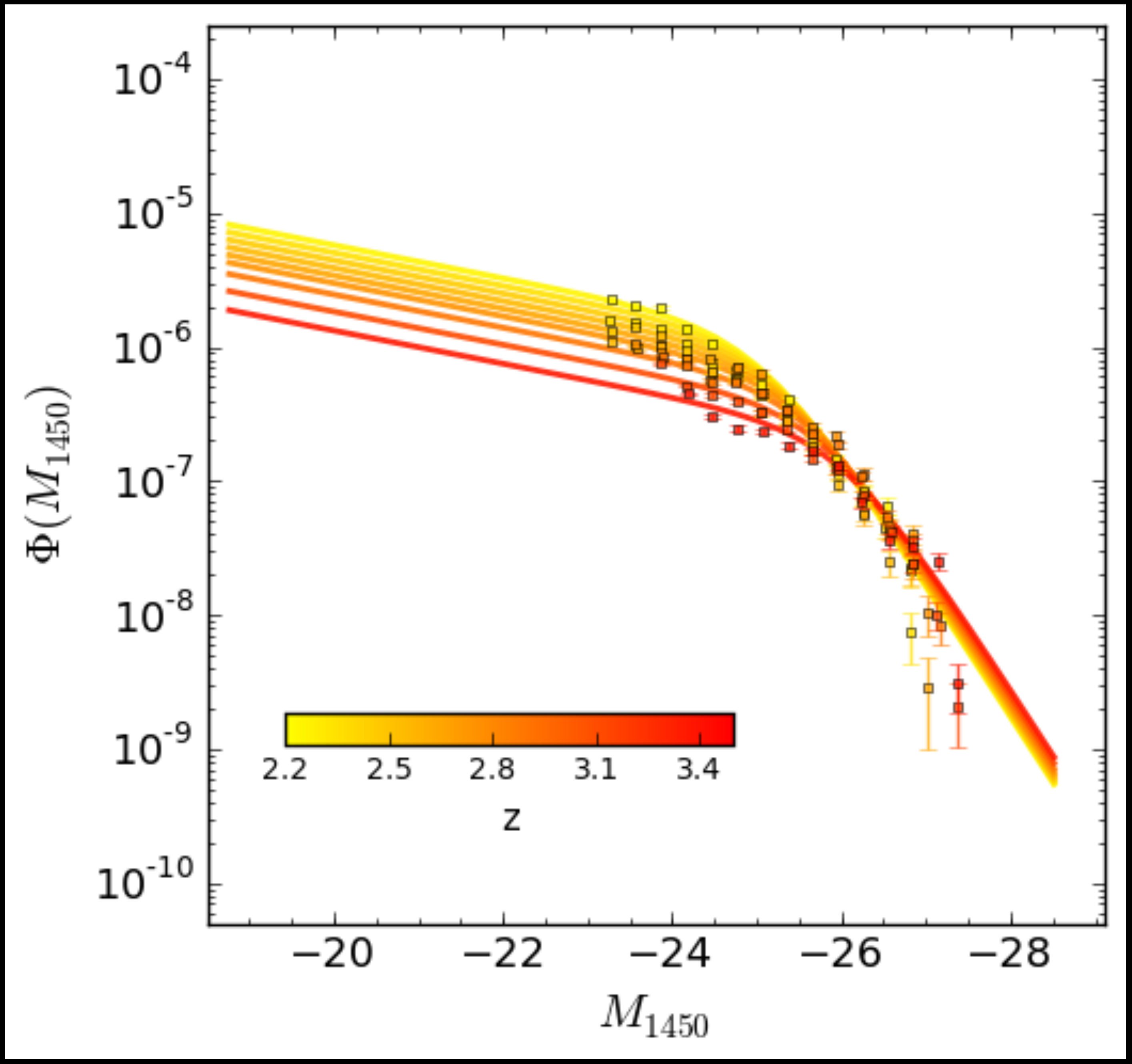
The quasar luminosity function

$$\Phi(L, z) = \frac{\phi_*^{(L)}}{(L/L^*)^\alpha + (L/L^*)^\beta}$$



Hopkins, Richards, & Hernquist 2007

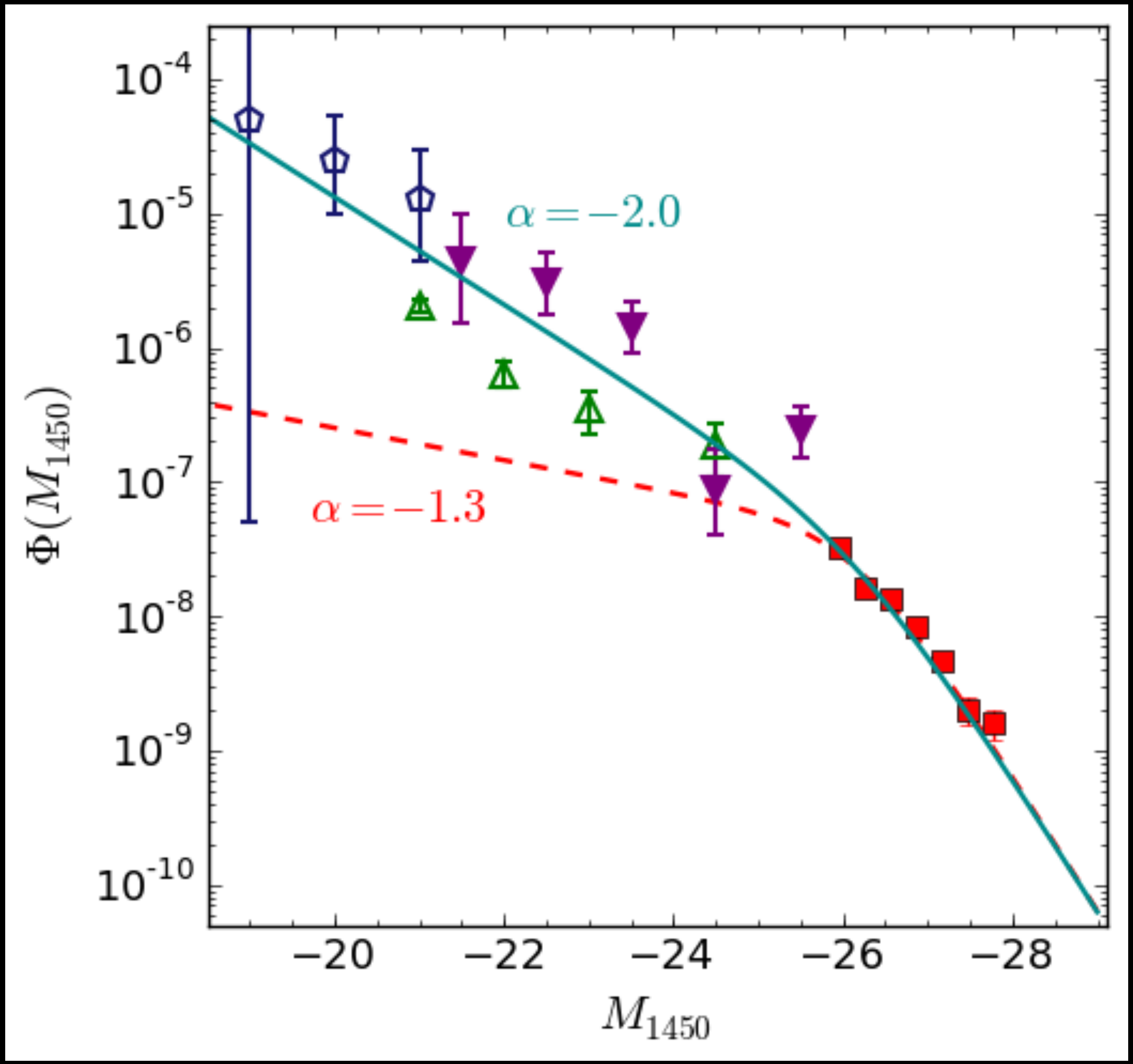
State of the quasar census: z=2.2–3.5 QLF



BOSS DR9 (Ross, IDM et al. 2013)

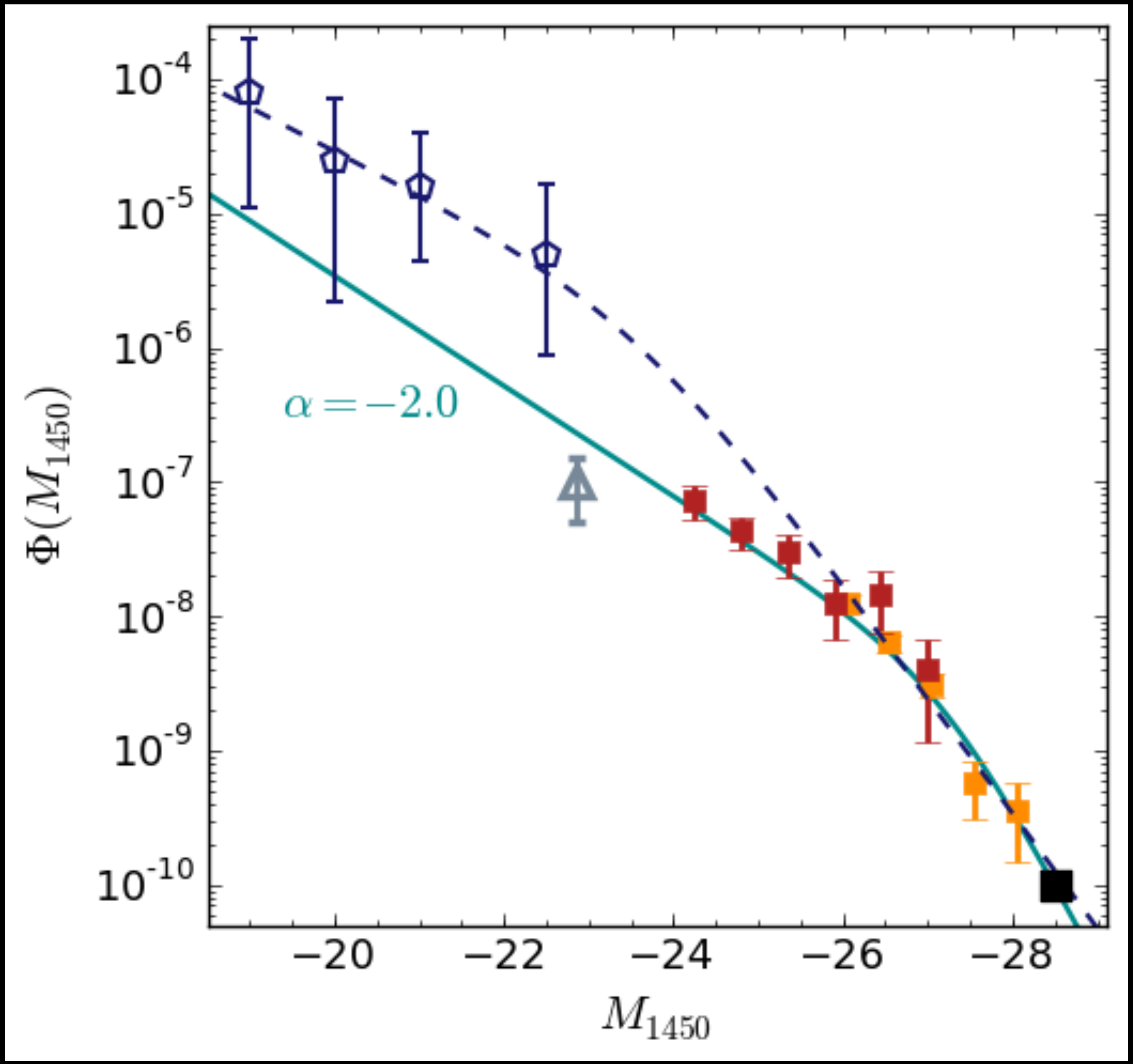
- only 1/6th of data analyzed
- systematics-limited
- little evolution in bright end
- strong density evolution, PLE ruled out LDDE (e.g., HRH07) strongly disfavored
- independent luminosity and density evolution (LEDE)

State of the quasar census: z=4 QLF



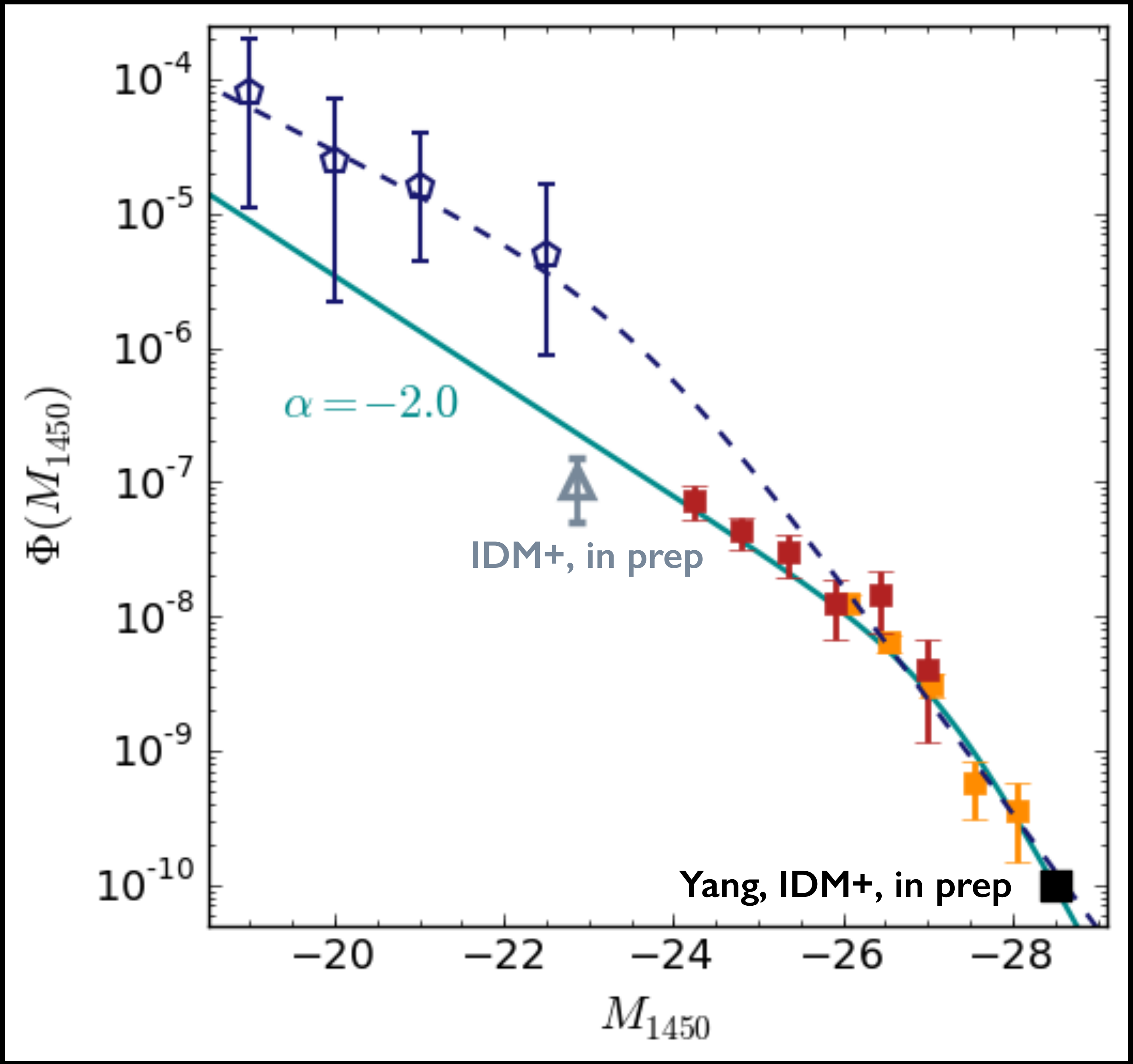
- factor of ~5 discrepancy at faint end
  - NDWFS (Glikman+11)
  - COSMOS (Masters+12)
  - GOODS fields (Giallongo+15)
- faint slope appears to steepen

State of the quasar census: z=5 QLF



- SDSS main + deep (IDM+14)
- GOODS fields (Giallongo+15)
- faint quasars with Gemini spectroscopy (IDM+, in prep)
- consistent with steep faint end slope and high break luminosity

State of the quasar census: z=5 QLF



- SDSS main + deep (IDM+14)
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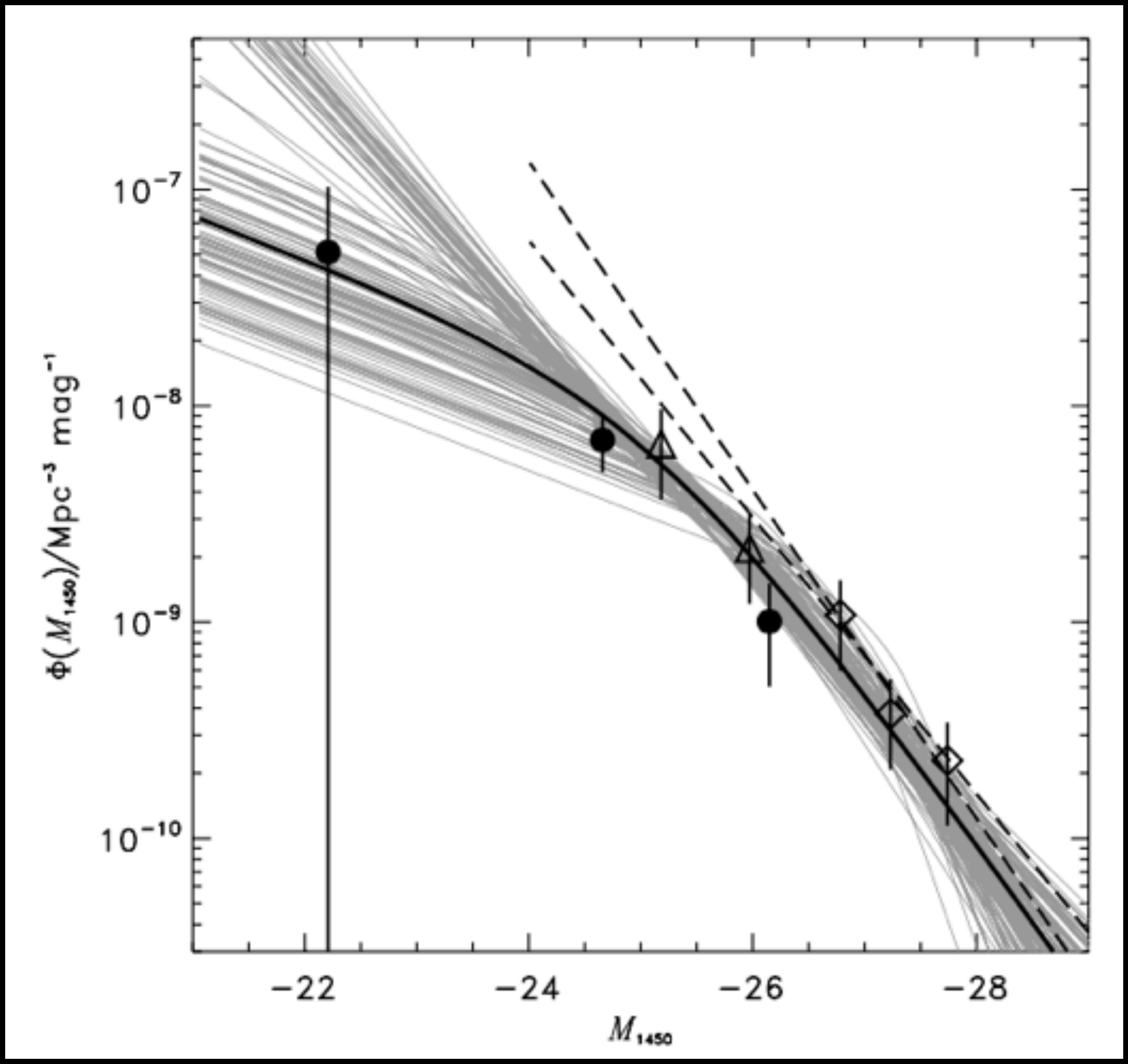
- faint quasars with Gemini spectroscopy (IDM+, in prep)
- consistent with steep faint end slope and high break luminosity

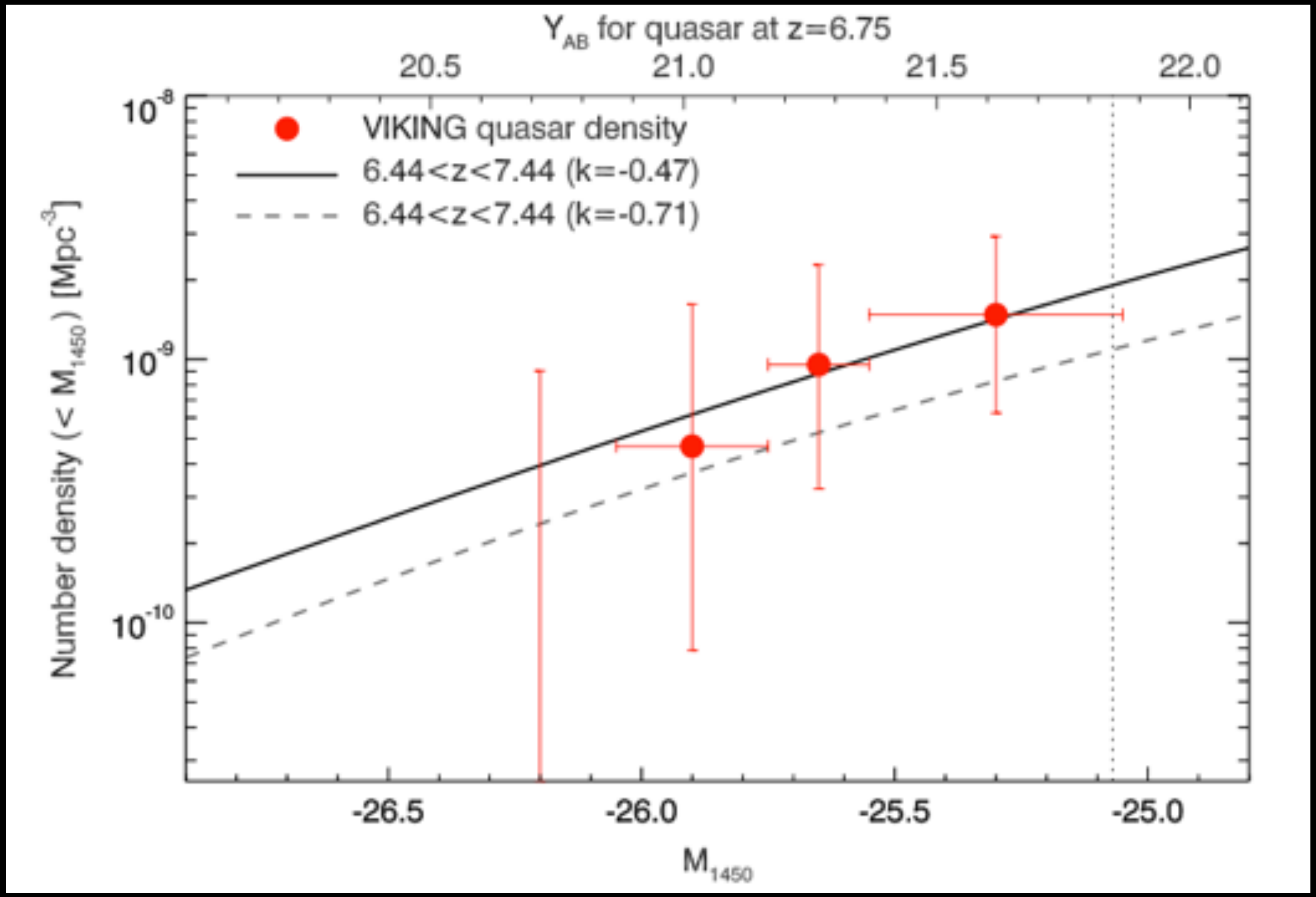
State of the quasar census: z=6 QLF



Willott+11

- now ~140 quasars
- Pan-STARRS filling out bright end
- constraints from gravitational lensing agree with high M* (IDM+, in prep)

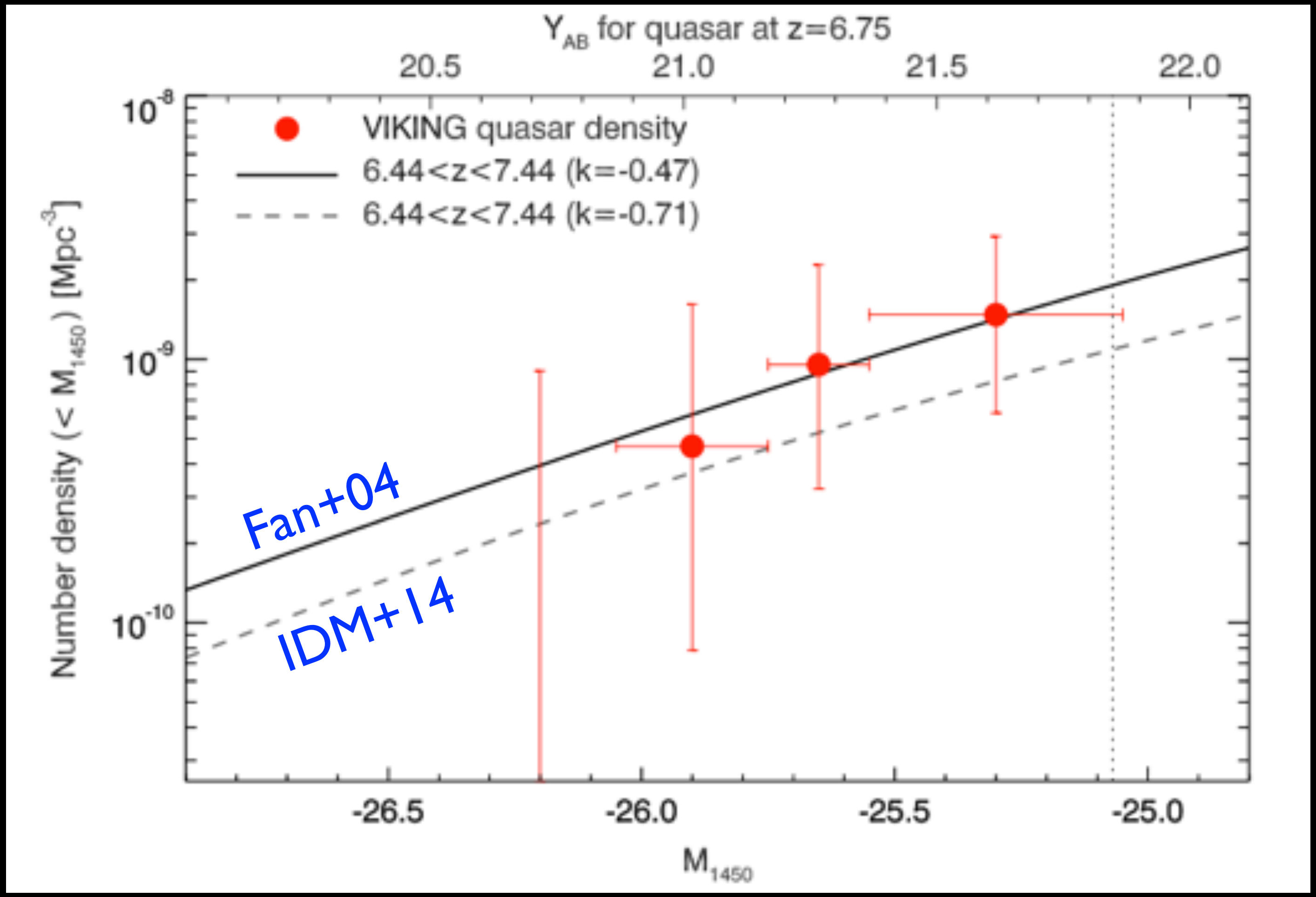
State of the quasar census: z=7 QLF



Venemans+13

- 1 z>7 QSO from UKIDSS (Mortlock+11)
- 3 z>6.5 QSOs from VIKING (Venemans +13)
- 3 z>6.5 QSOs from Pan-STARRS (Venemans+15)

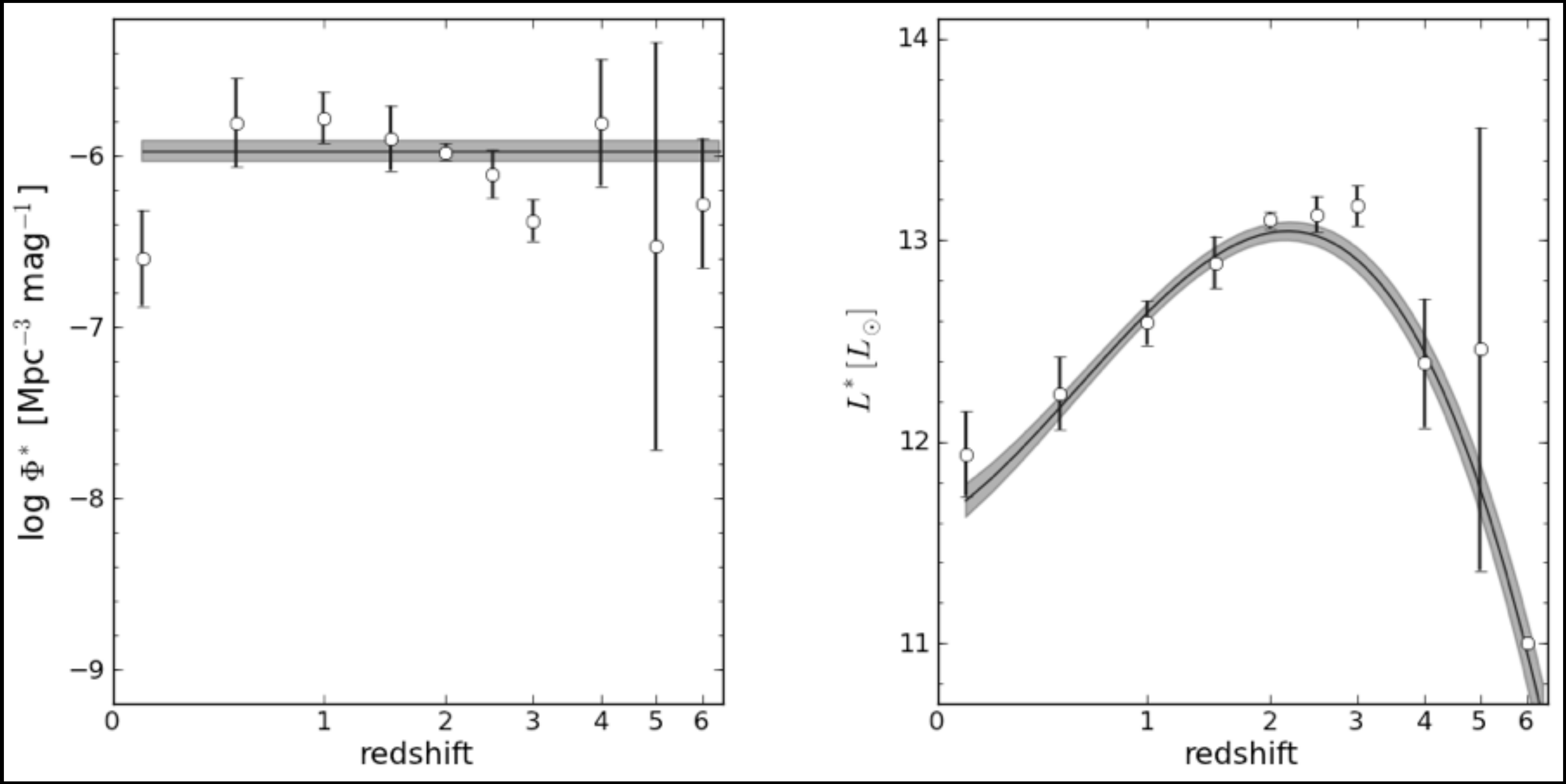
State of the quasar census: z=7 QLF



Venemans+13

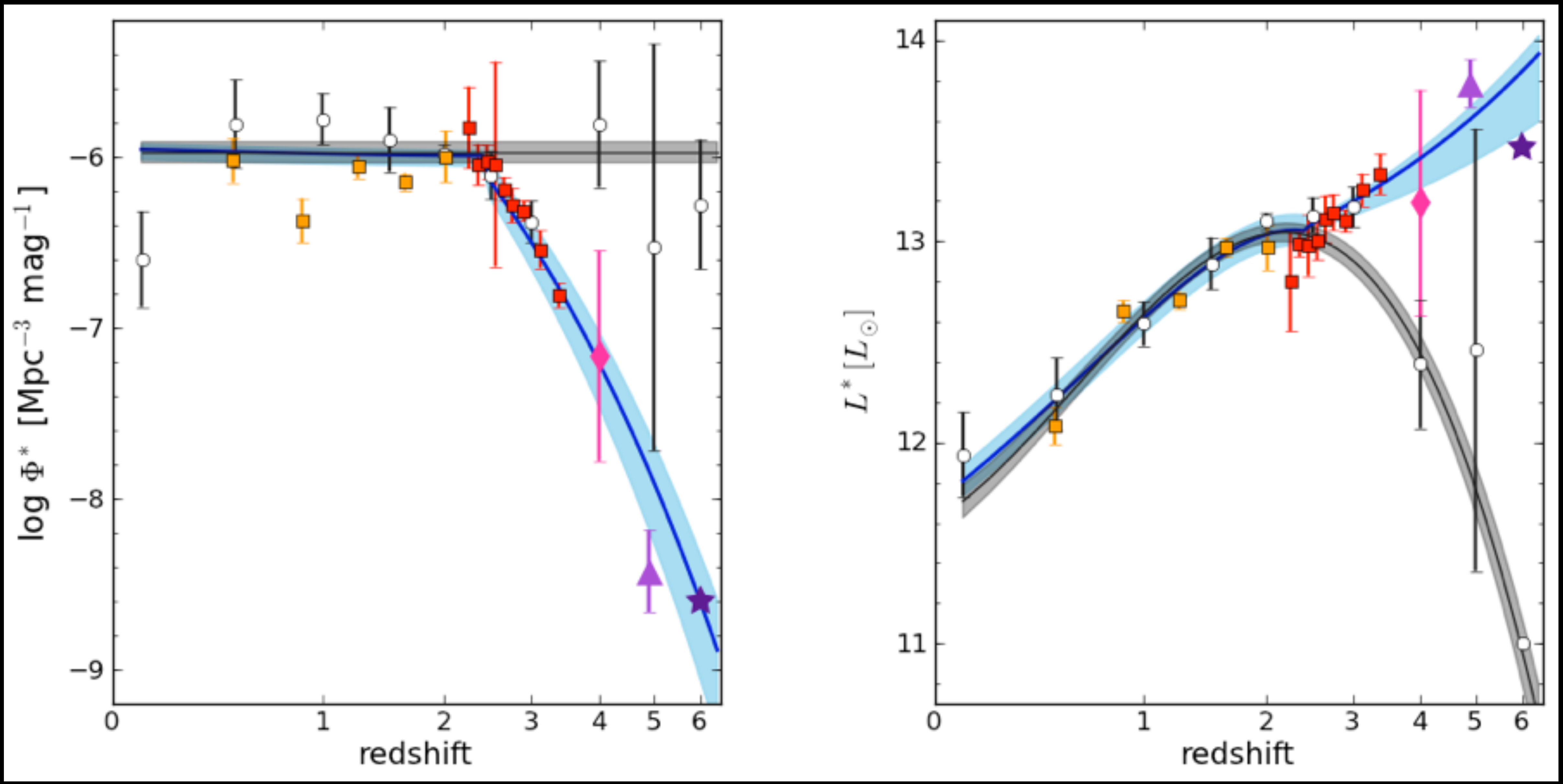
- 1 z>7 QSO from UKIDSS (Mortlock+11)
- 3 z>6.5 QSOs from VIKING (Venemans +13)
- 3 z>6.5 QSOs from Pan-STARRS (Venemans+15)

State of the quasar census: evolutionary models



gray: HRH07

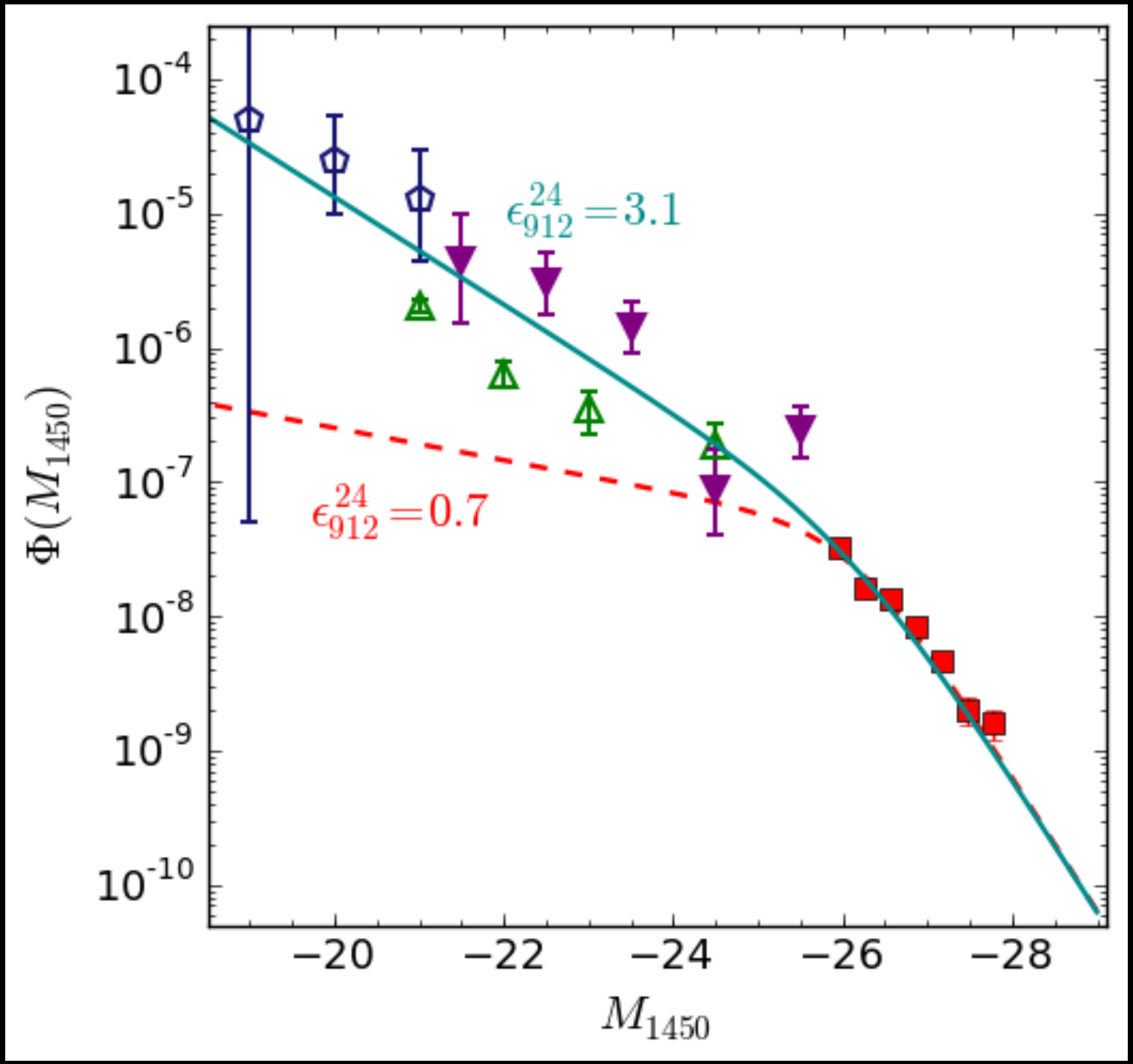
State of the quasar census: evolutionary models



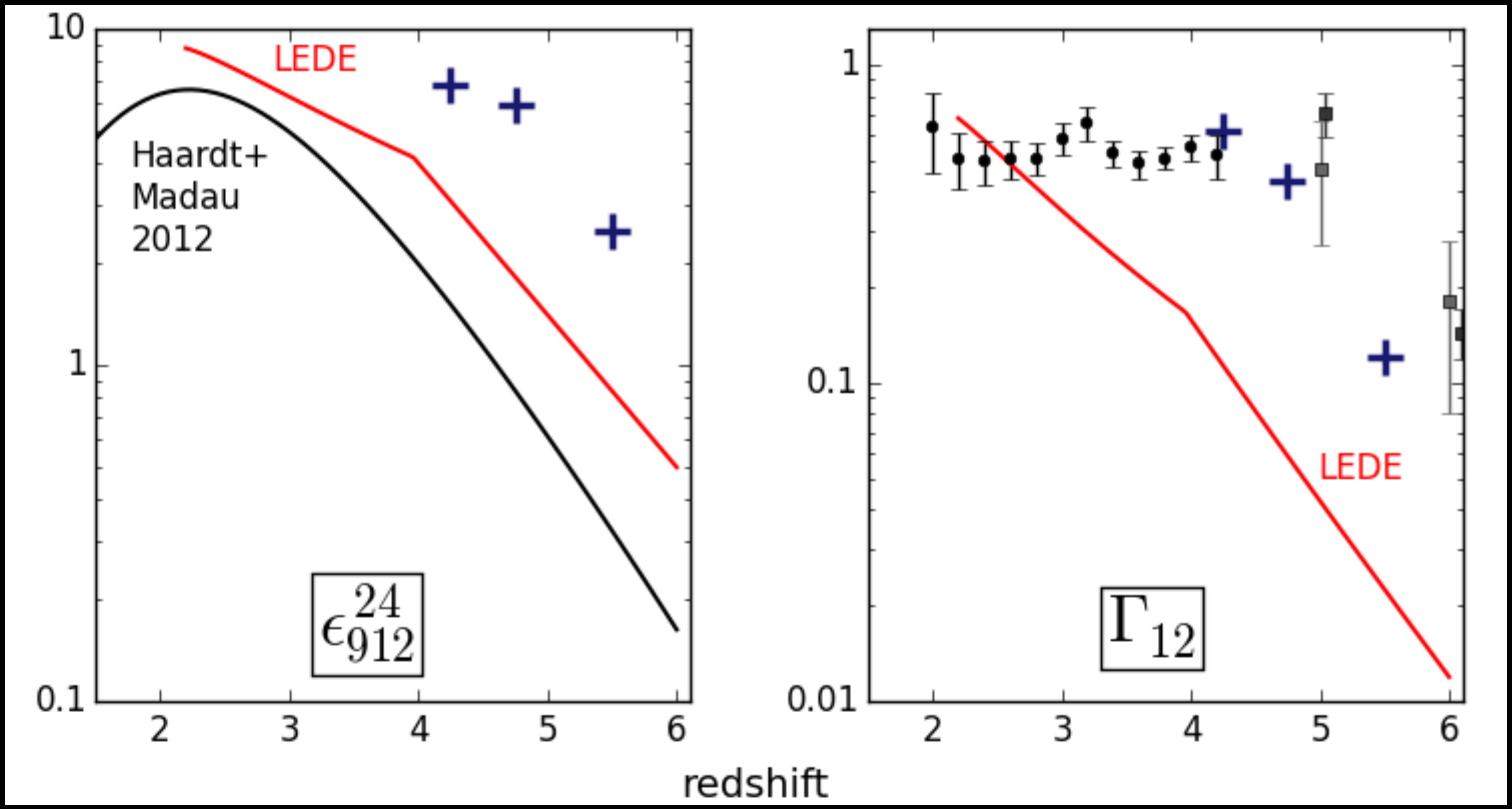
gray: HRH07

BOSS (Ross, IDM +14)
COSMOS (Masters+12)
SDSS (IDM+14)
CFHTQS (Willott+12)

ionizing emissivity from z=4 QLF

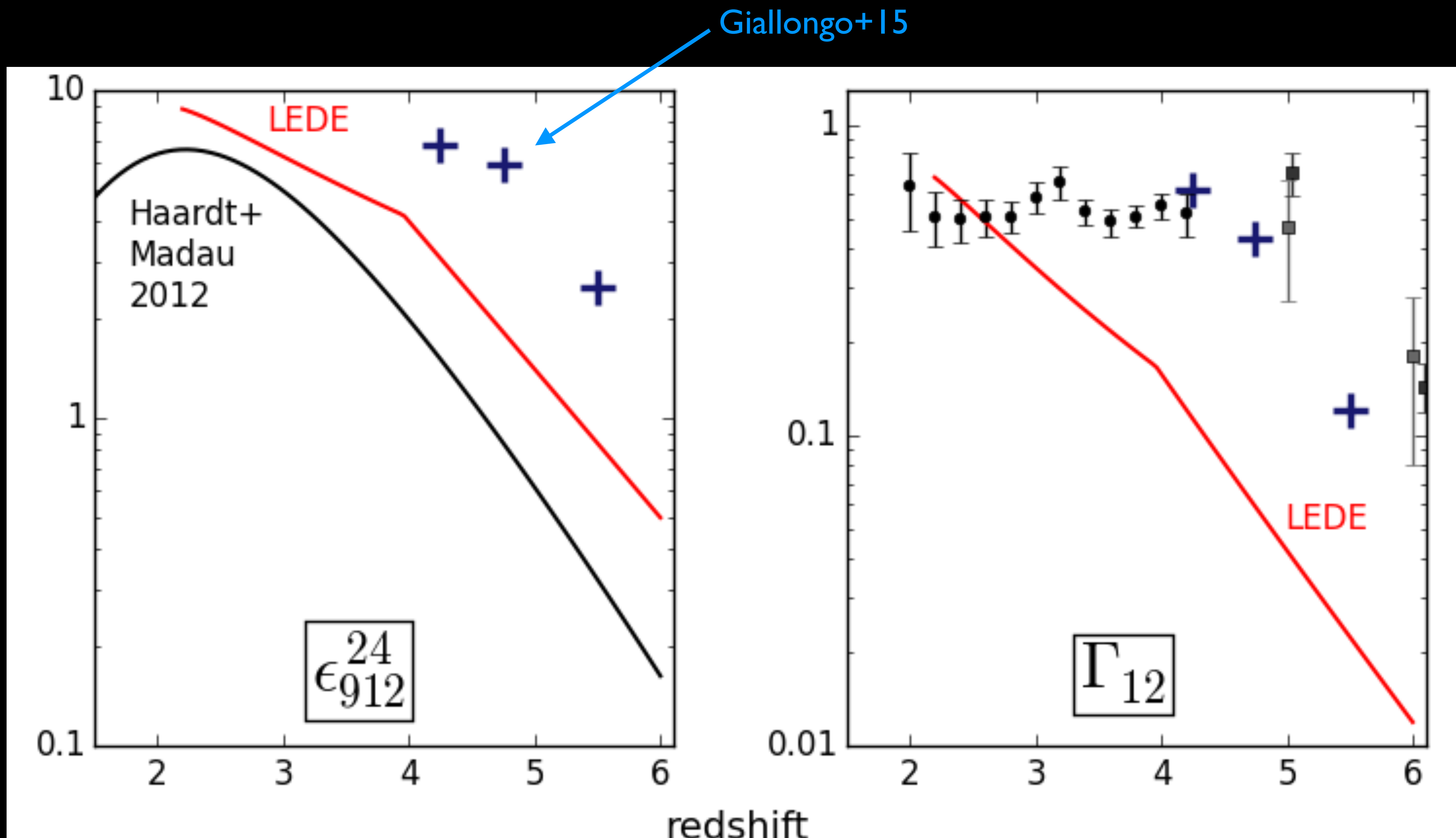


evolution of quasar ionizing background



Data from
Faucher-Giguere+08,
Wyithe+Bolton`10,
Calverley+11

evolution of quasar ionizing background



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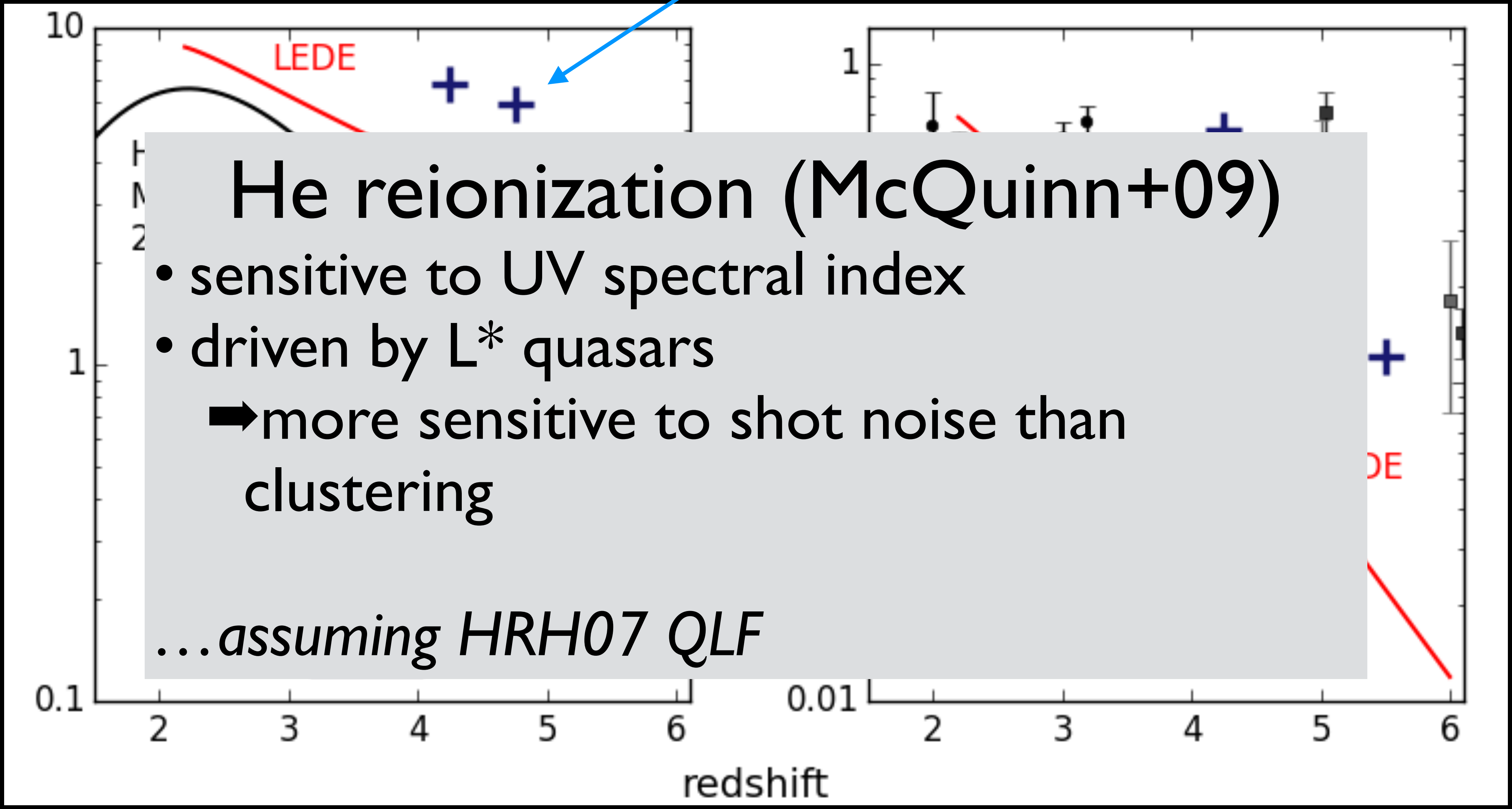
Calverley+11

evolution of quasar ionizing background

Giallongo+15



He reionization (McQuinn+09)

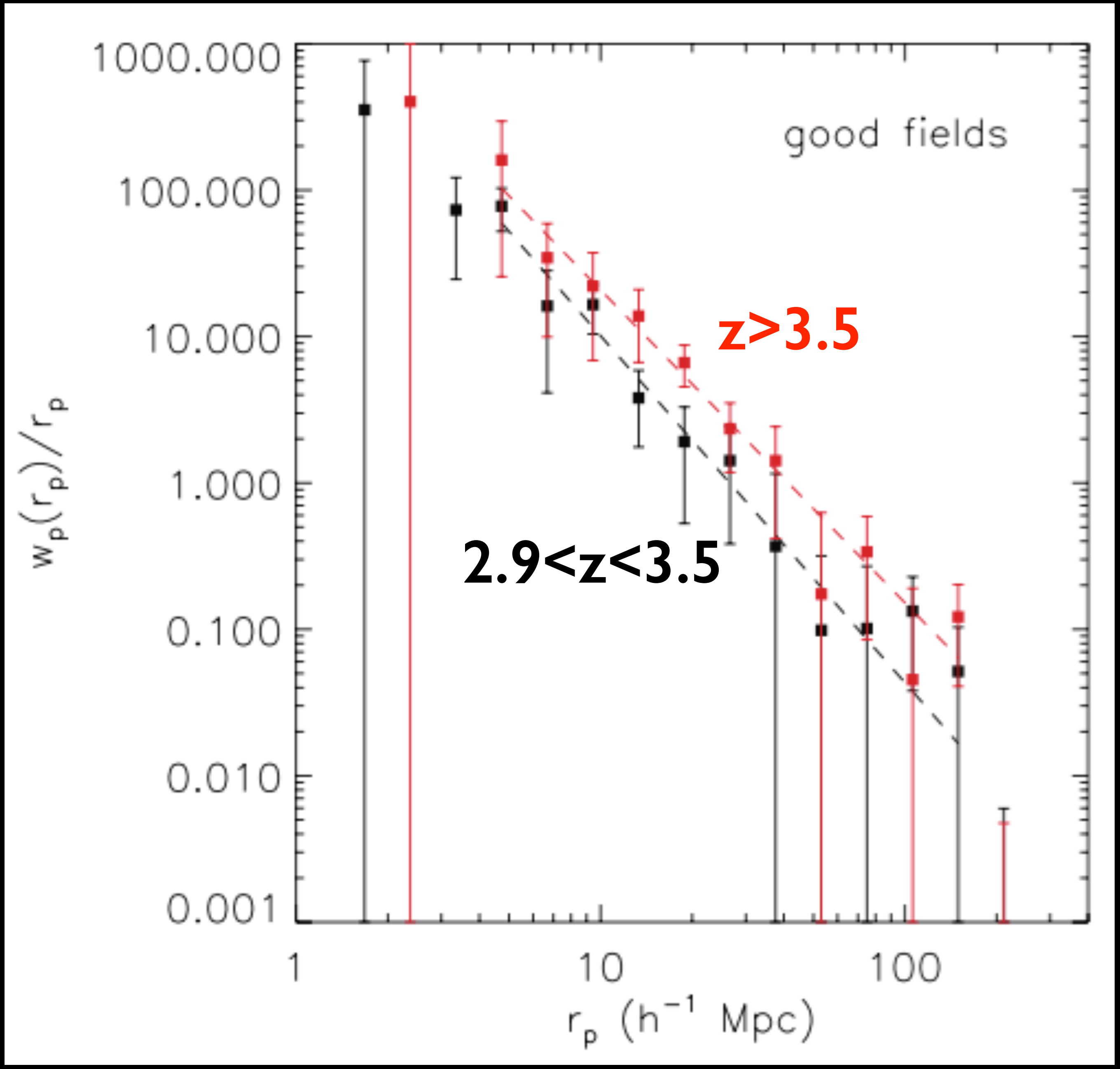
- sensitive to UV spectral index
- driven by L* quasars
  - ➡more sensitive to shot noise than clustering

…assuming HRH07 QLF

Data from Faucher-Giguere+08, Wyithe+Bolton`10, Calverley+11

Part III: clustering

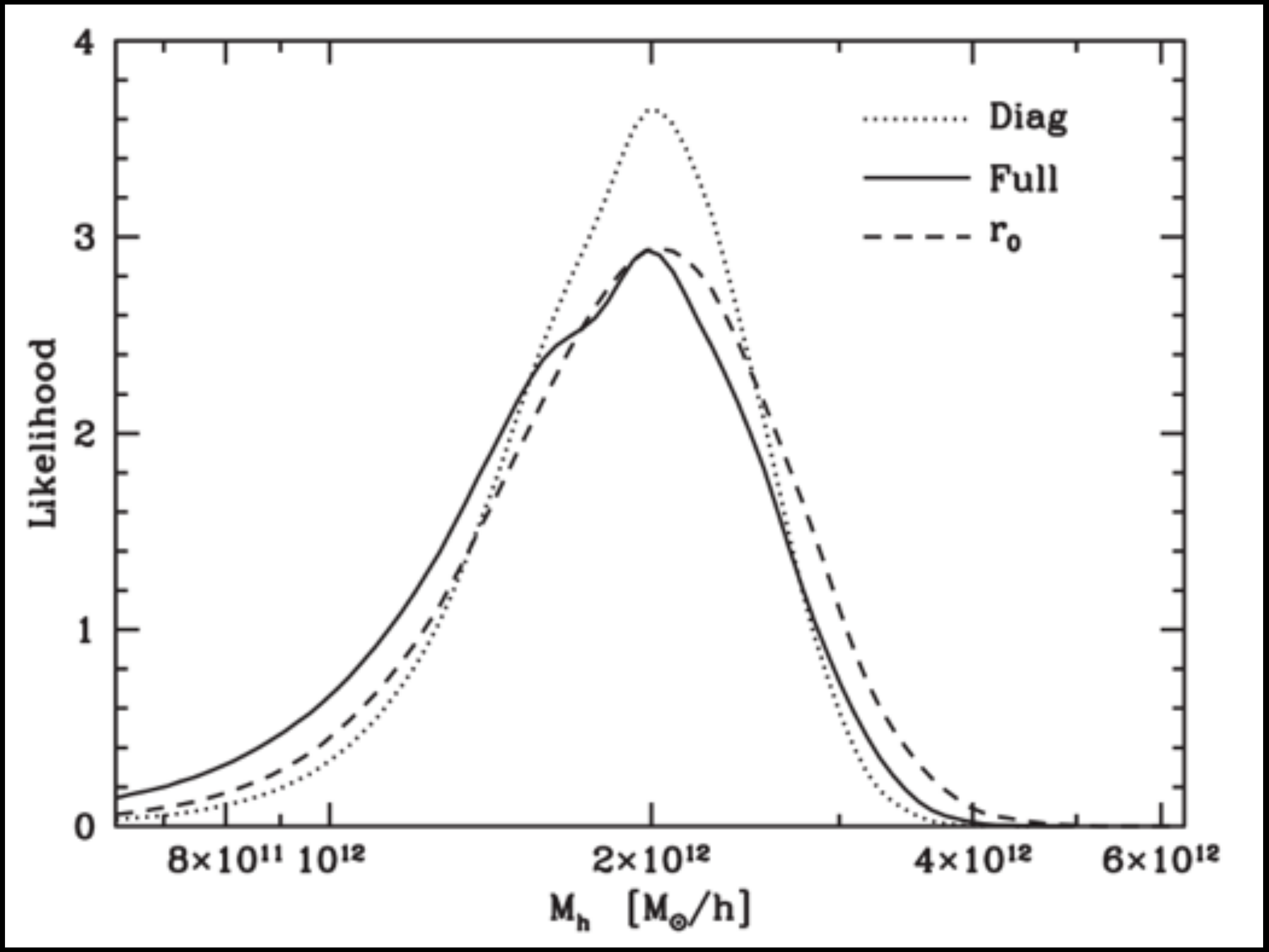
high redshift quasar clustering: measurements



Shen+07

- SDSS ~4K quasars (Shen+07)
- BOSS ~27K quasars (White+12)
- Transverse Proximity Effect / absorber correlations (Prochaska+13)
- quasar pairs at z>4 (Schneider+00, Hennawi+06, Shen+10)

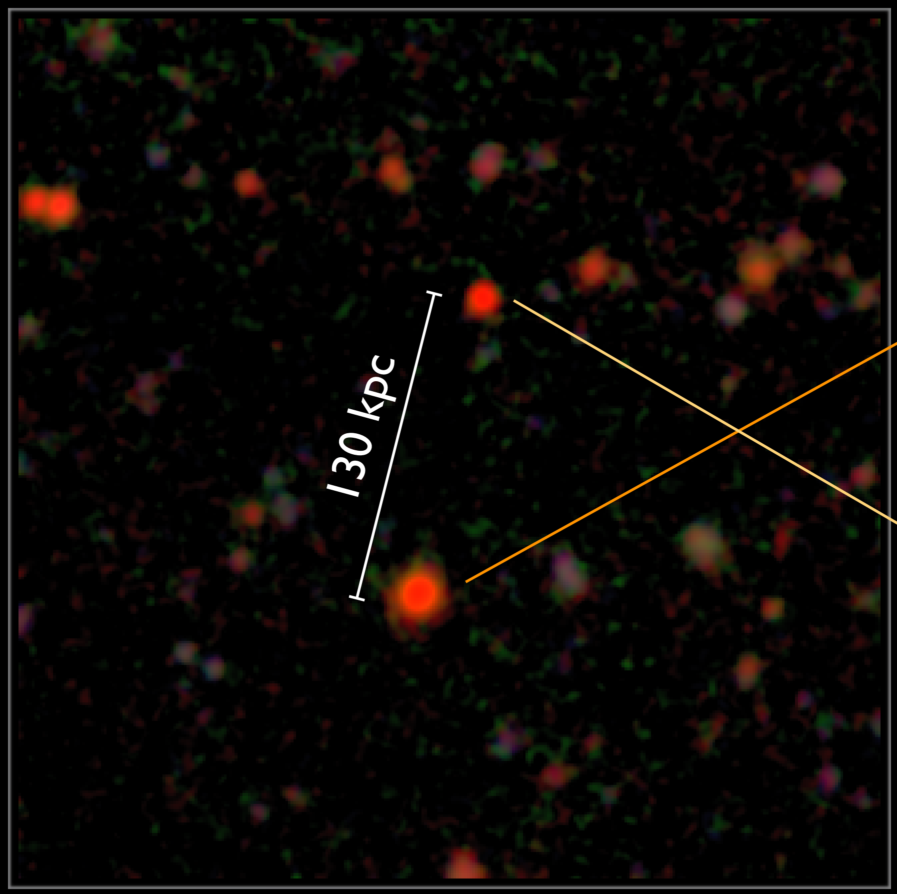
high redshift quasar clustering: measurements

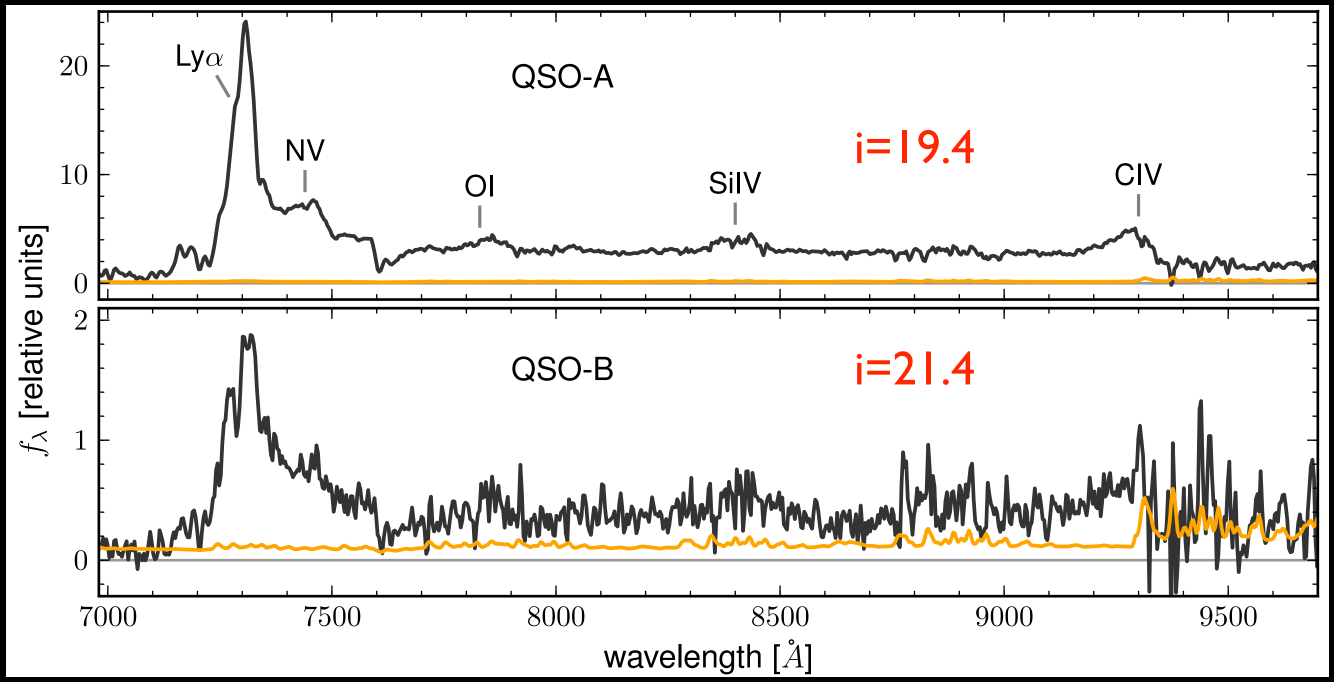


White+12

- SDSS ~4K quasars (Shen+07)
- BOSS ~27K quasars (White+12)
- Transverse Proximity Effect / absorber correlations (Prochaska+13)
- quasar pairs at z>4 (Schneider+00, Hennawi+06, Shen+10)
- weak luminosity dependence at low-z (Adelberger+Steidel`05,Lidz+06, Shen+13,…)

high redshift quasar clustering: a new z=5 binary

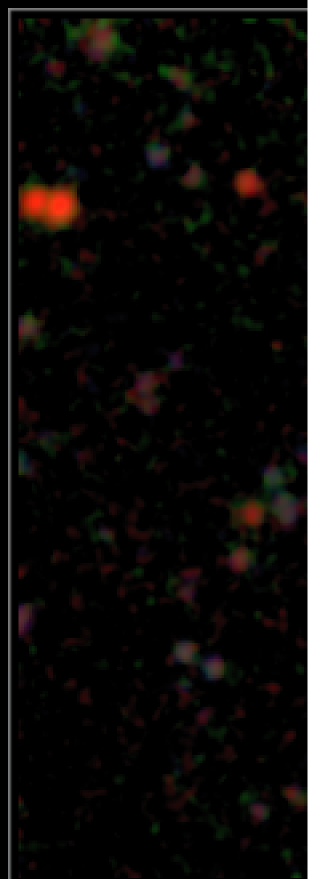


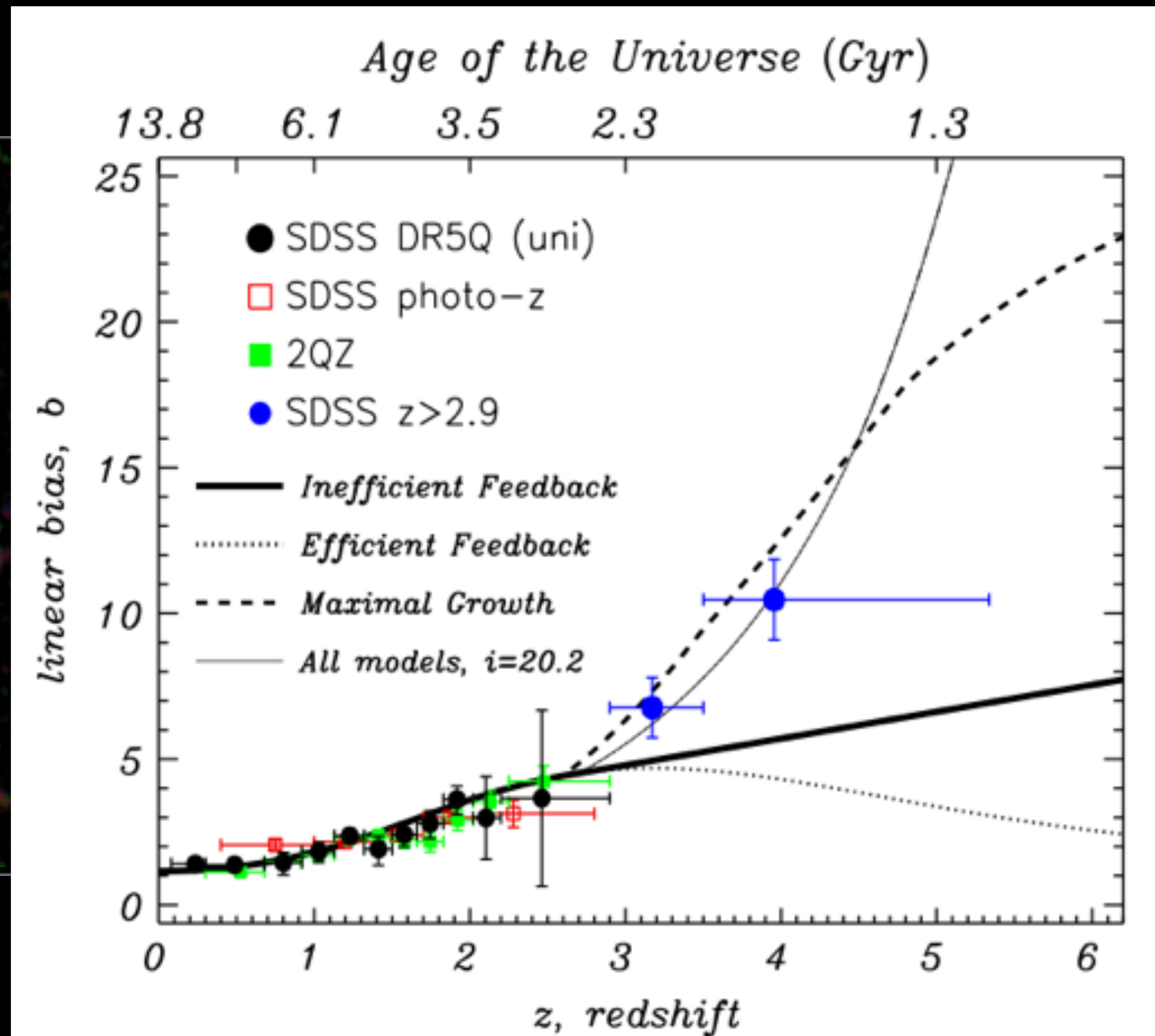


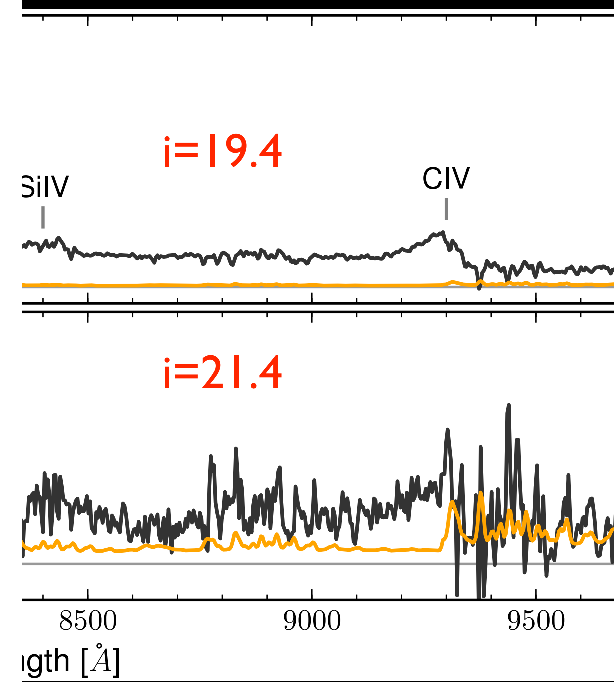
IDM, Eftekharzadeh, in prep

$r_0 > 30$ Mpc

high redshift quasar clustering: a new z=5 binary







M, Eftekharzadeh, in prep

Ross+09, after Hopkins+07

$r_0 > 30$ Mpc

Part IV: bright, reionization-epoch sources

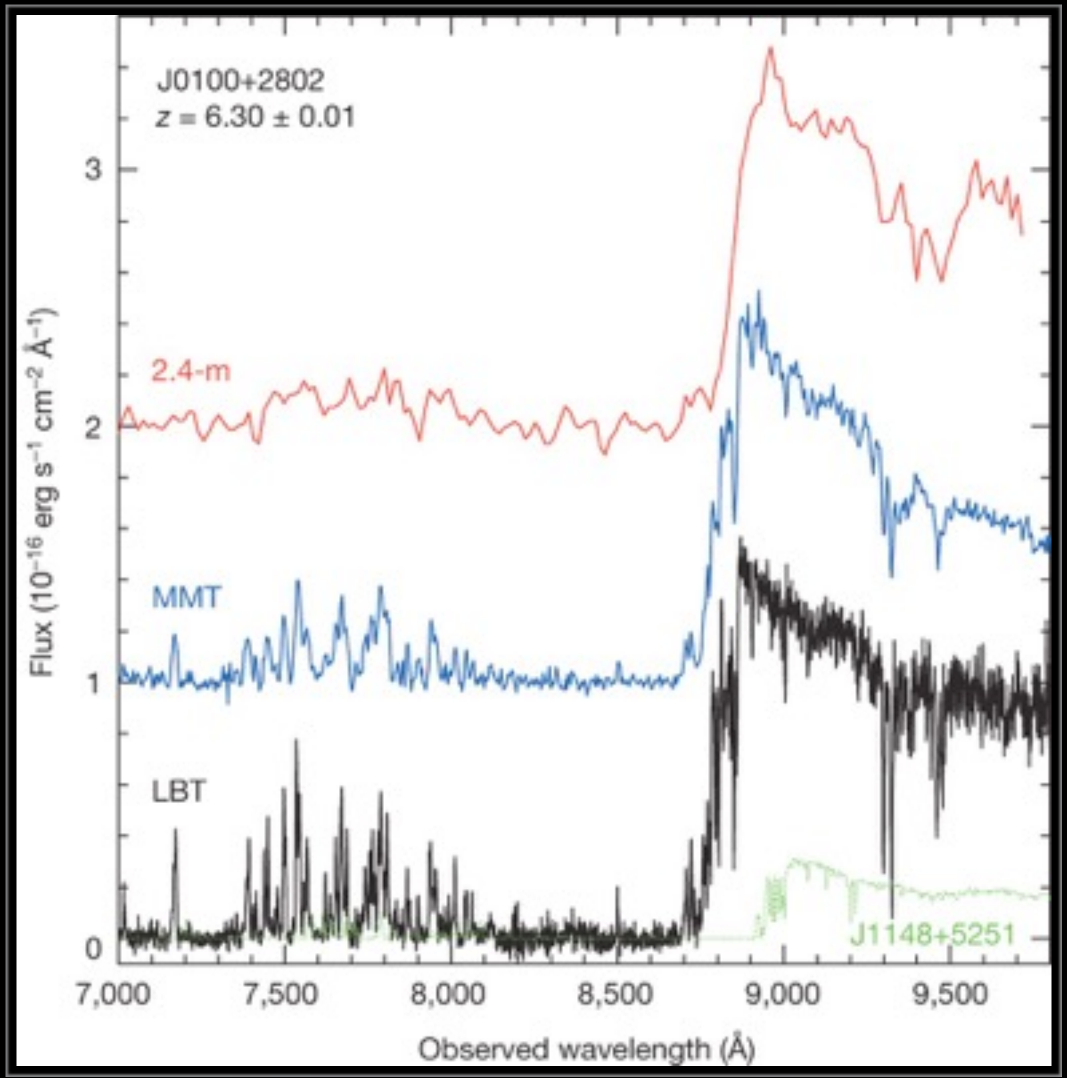
Prospects for bright reionization-epoch quasars

~140 quasars known at z>5.7 today

Ongoing wide-area searches:

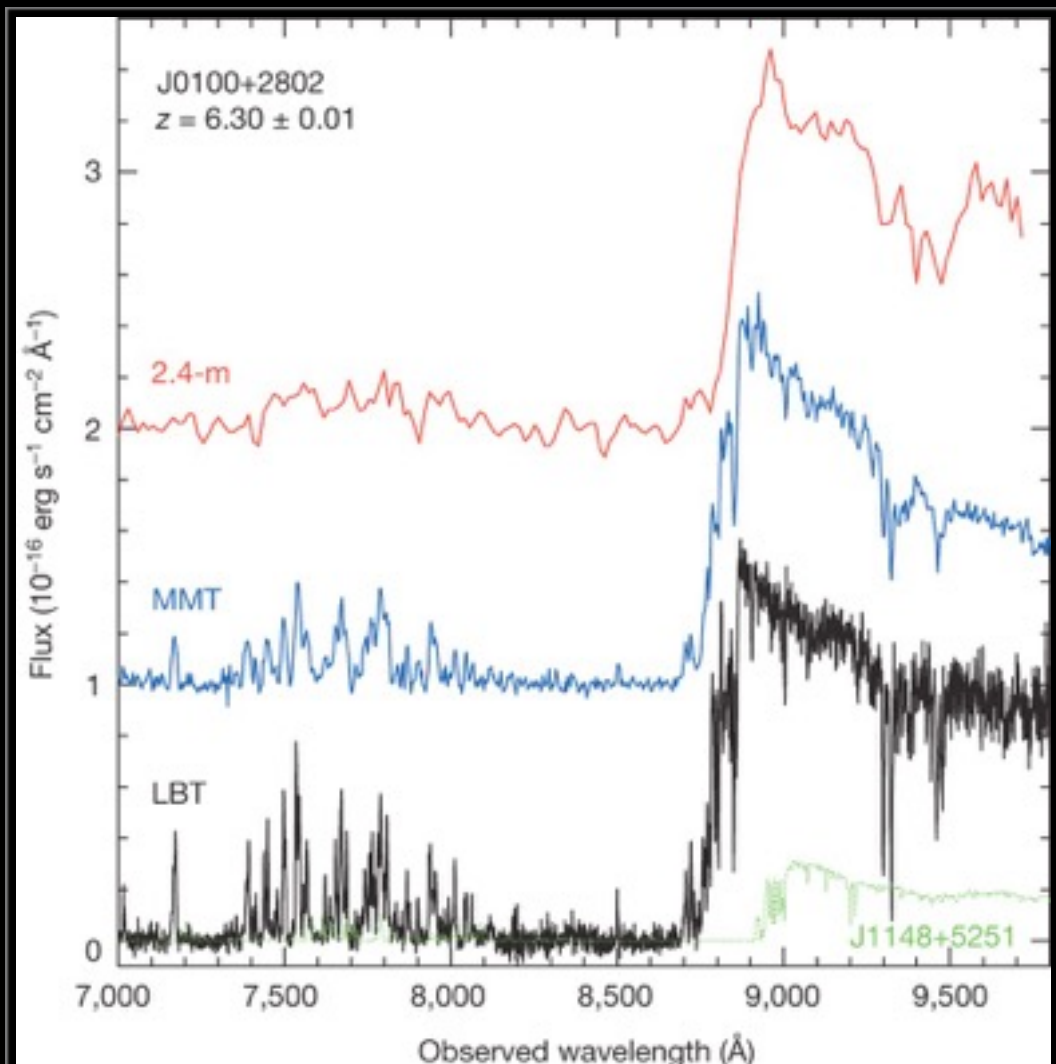
- Pan-STARRS (Morganson+12, Banados+14, Venemans+15)
  - ~20 reported to date, reaching z~6.7
- SDSS+WISE (Wu+12)
  - expanding on Fan et al. selection
- VST ATLAS (Carnall et al. 2015)
  - 5000 deg^2 SDSS-like in Southern Hem., ~40% of data so far
  - 3 z~6 QSOs with z~19.6

SDSS+WISE Ultra-luminous quasars



Wu et al. 2015
Nature 518, 7540, 512

SDSS+WISE Ultra-luminous quasars



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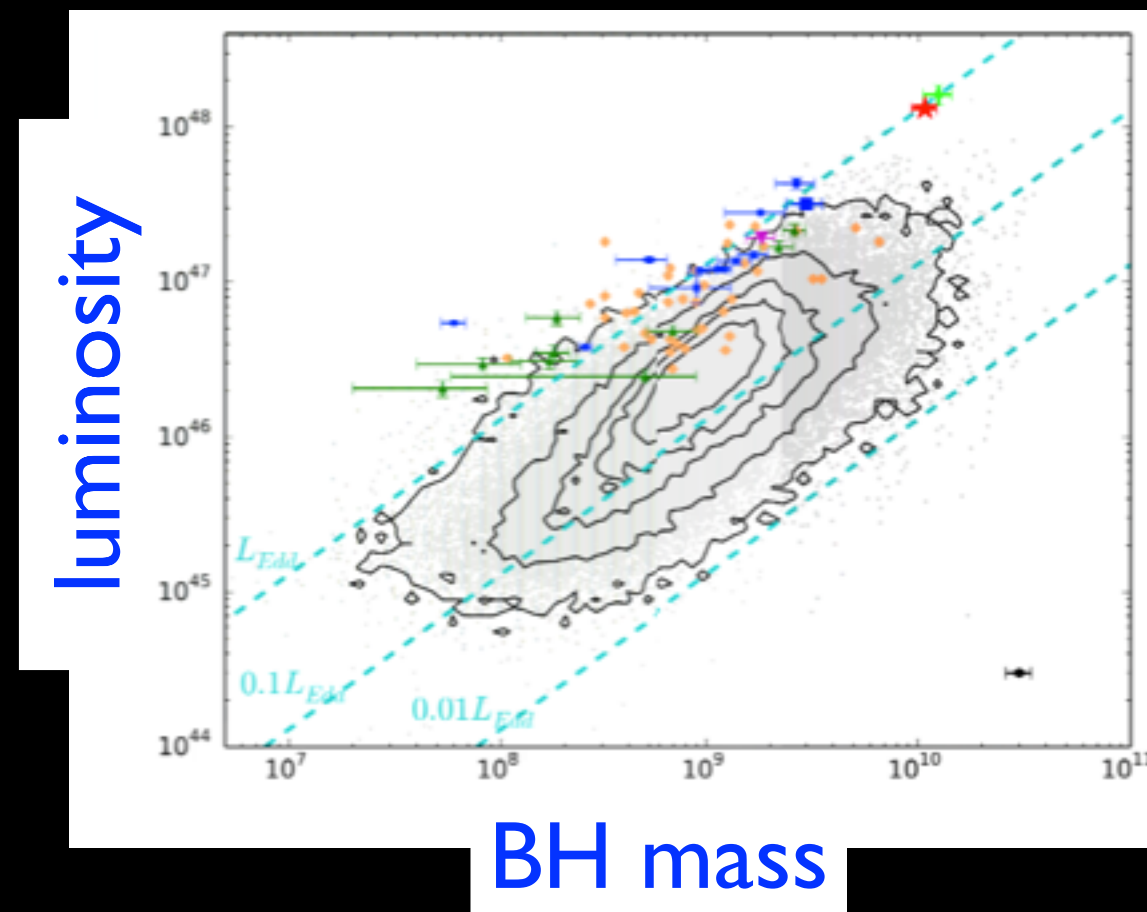

Wang et al. 2015 (submitted)

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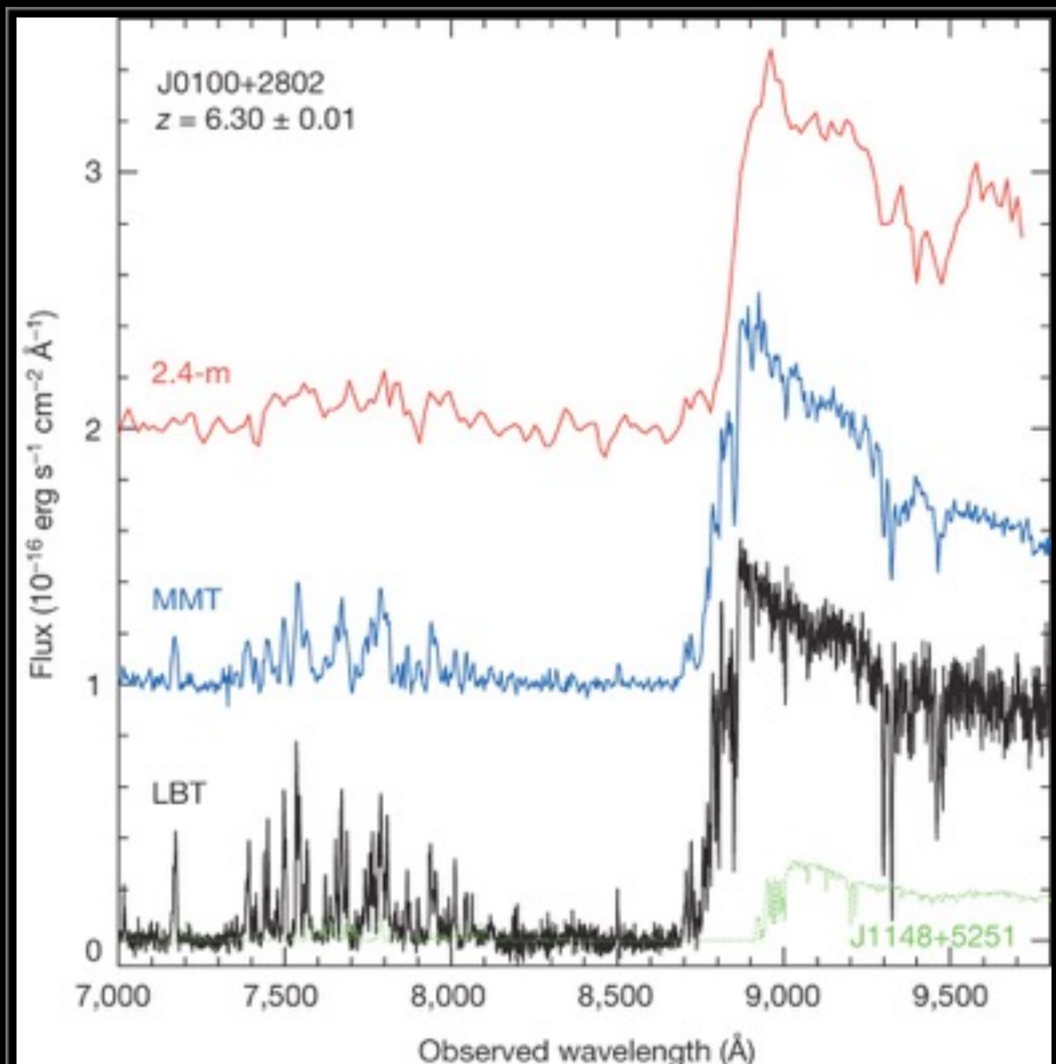

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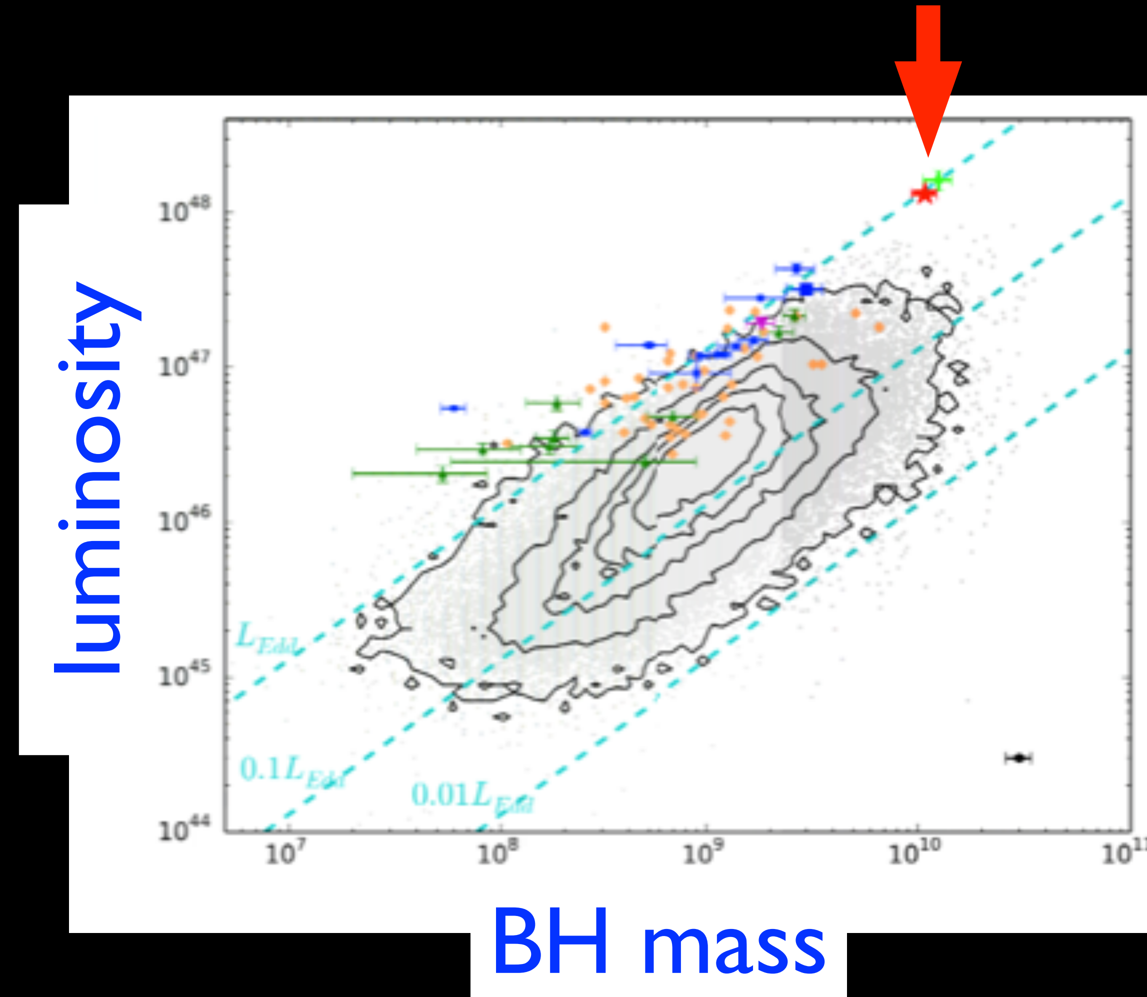

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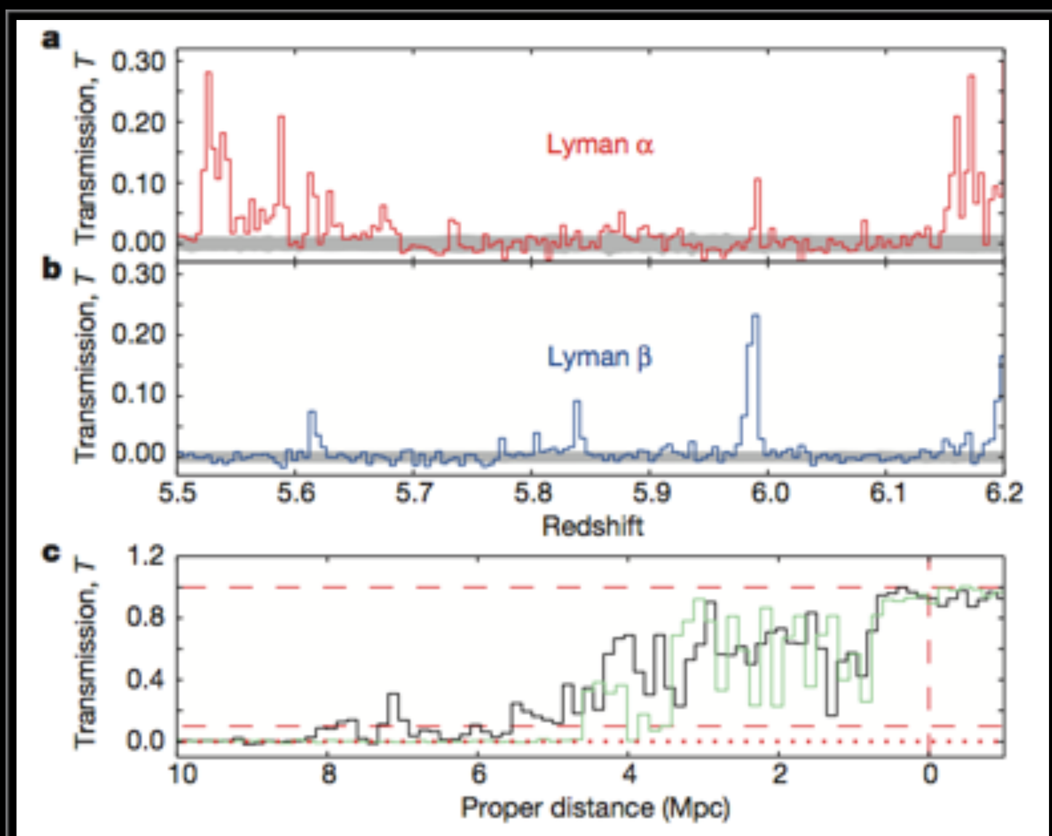

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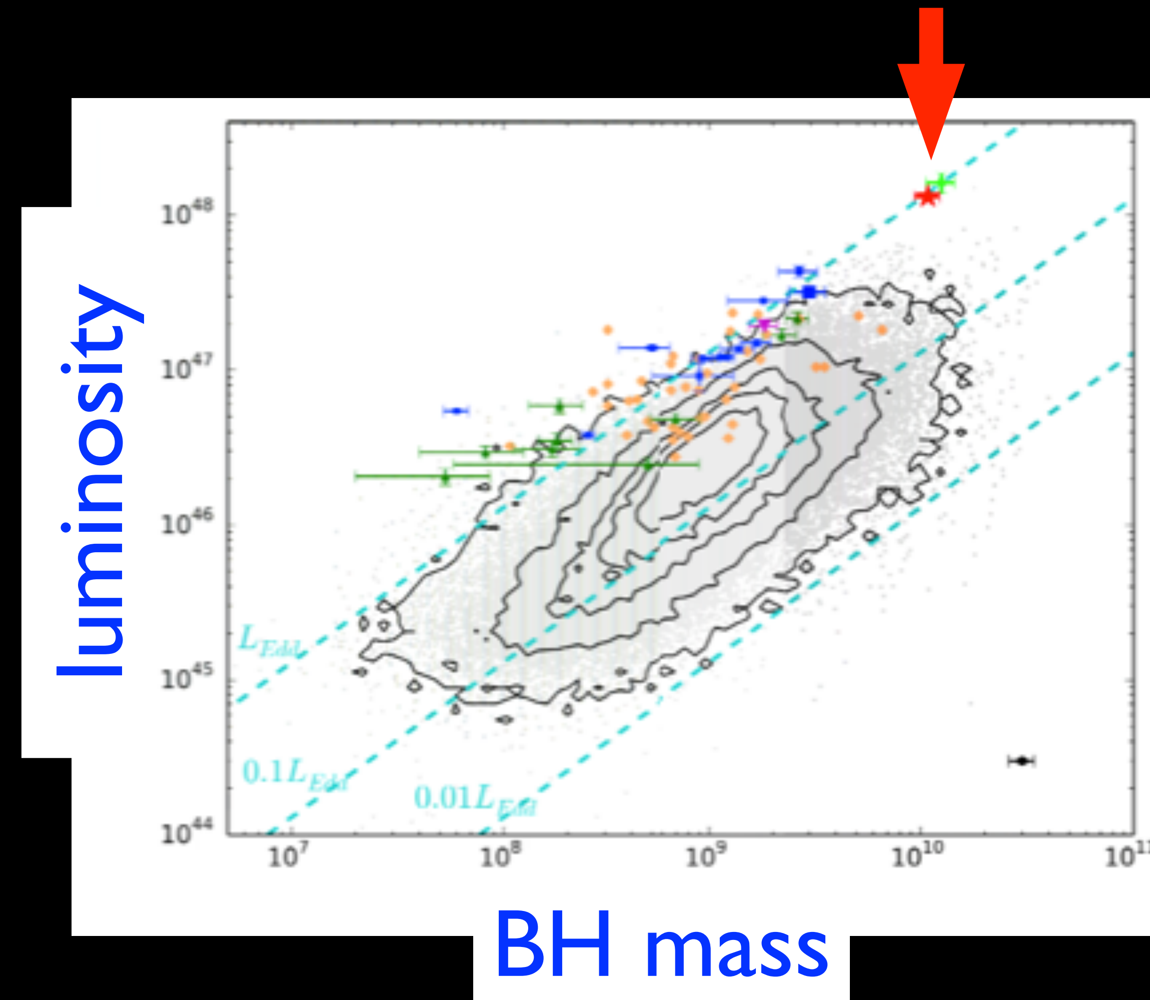

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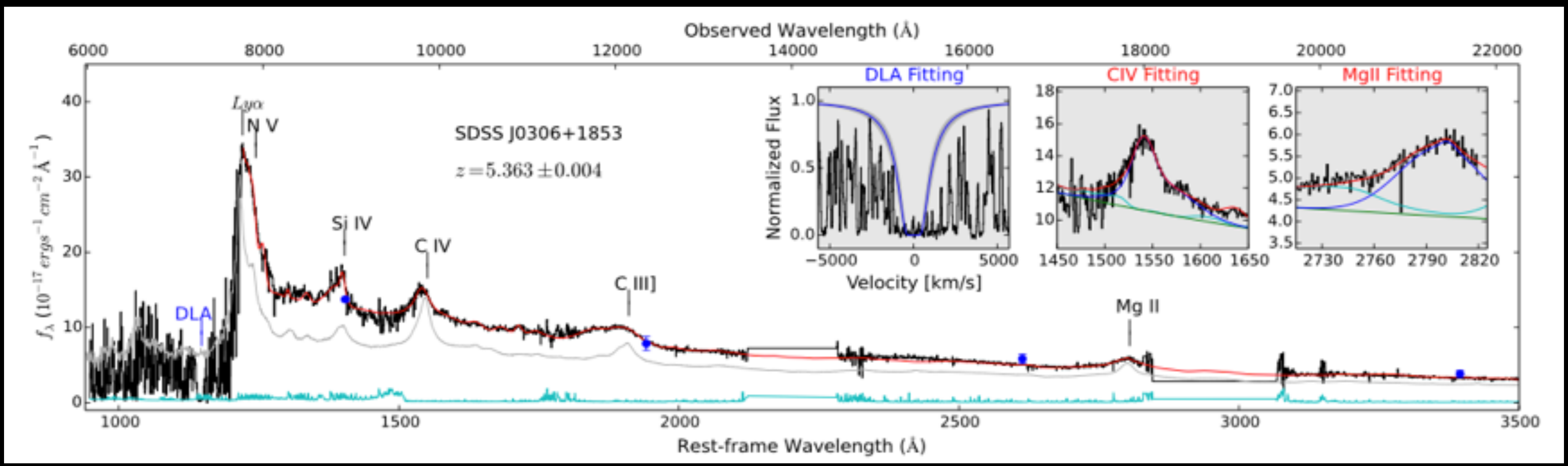

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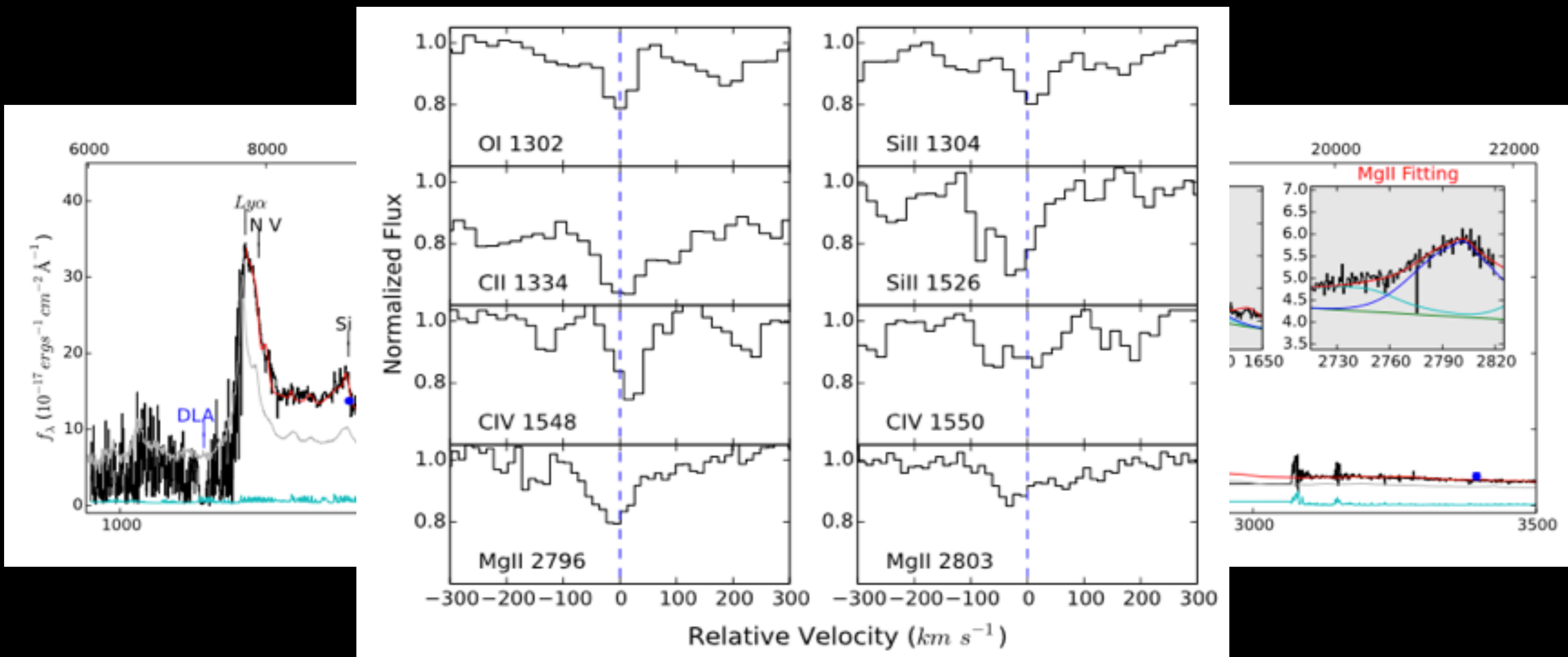
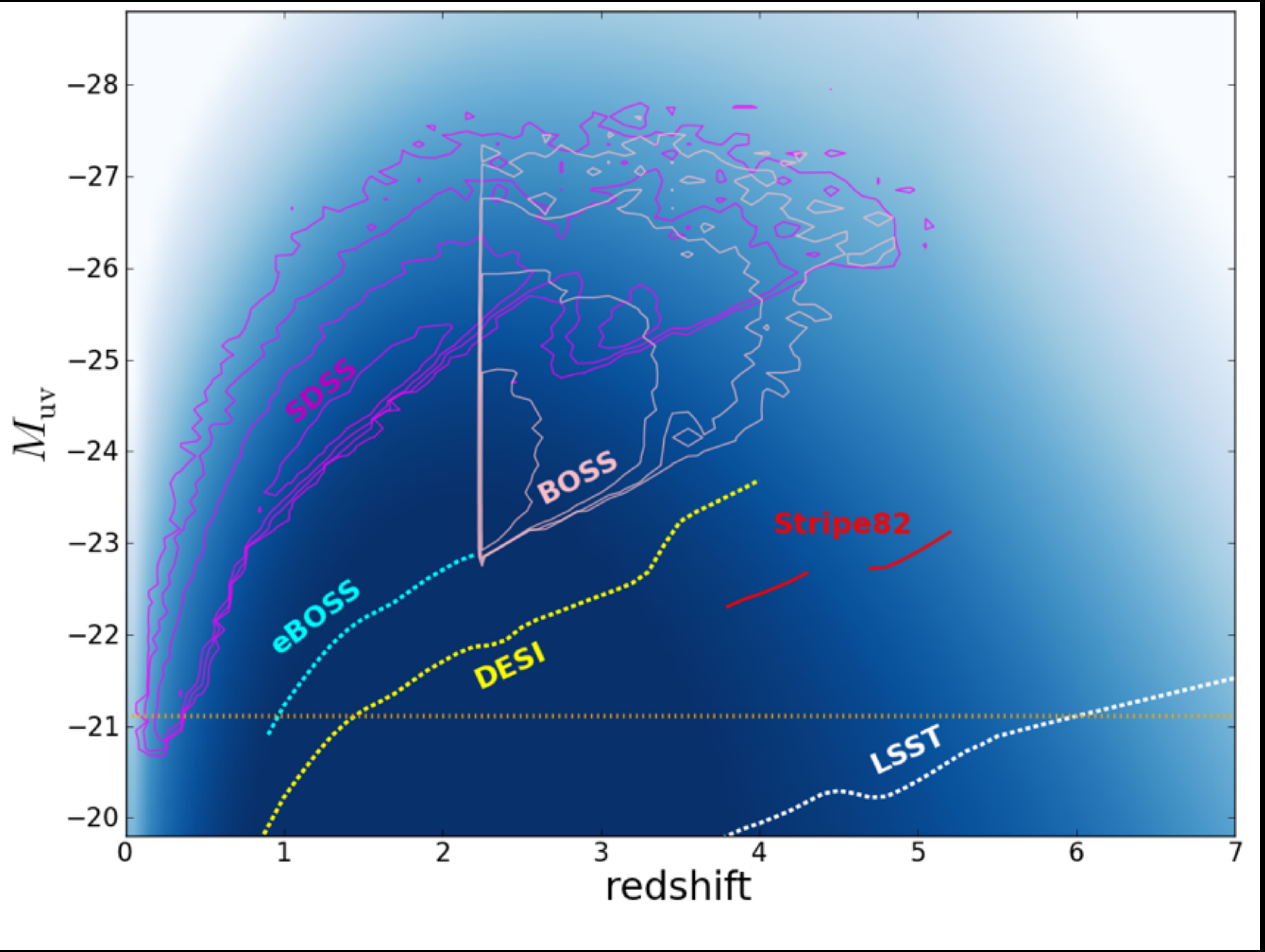


Wang et al. 2015 (submitted)

Part IV: future surveys

Quasar survey landscape, 2000-2030



Summary (hopefully not too depressing)

- Ionizing spectrum of quasars is poorly constrained, key input to (He) reionization models
- Factor of ~5 (or more) uncertainty in faint end QLF at z>3
- Quasars are strongly clustered at z>3, but t_{QSO}, BH mass -- halo mass relation poorly constrained